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Microgrid as a Power Reserve

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Abstract

The Finnish energy system is experiencing a sea change at the moment. The share of renewable energy is growing as the conventional electricity production is struggling. Earlier, the conventional power plants have been able to provide the flexibility that is needed to maintain the power balance, but with the weather-dependent renewables, it isn't anymore a viable option.

Instead the energy consumption must start to be flexible. The solution presented in this Master's thesis is one of the first commercial microgrids in the world, in which building automation is used to control loads such as ventilation and lighting in real-time in order to maintain the power balance in the society. This thesis has been written as a case study of a shopping center, where a solar power system and a battery with the power of 1.6 MW and capacity of 2.0 MWh are installed as parts of the microgrid too.

The Finnish transmission system operator Fingrid has created open reserve markets which allow the microgrid to participate the power balance regulation as a reserve. In this thesis it has been examined, how a microgrid can participate these markets and how great the benefits could be. Also the principles are introduced, how such a microgrid could be operated so that the indoor conditions wouldn't become intolerable and the people inside the building wouldn't notice anything.

The solution can create new sources of income for the property owners and also can allow more accurate energy management in the future. The potential income has been modelled in the thesis.

At the same time the microgrid solution has a high potential to be a cheaper alternative for the reserve and backup power plants, that would be needed to maintain the power balance in the grid. If the demand response solution became more common, the society could gain significant savings, when there wouldn't be need to invest into expensive power plants that are running only during the peak demands.

Keywords microgrid, power reserve, demand response, smart energy system, power balance, building technology, shopping center

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Tiivistelmä

Suomen energiajärjestelmä on käännekohdassa. Uusiutuvan energian tuotannon osuus kasvaa samalla kun perinteinen sähkön tuotanto on vaikeuksissa. Perinteisesti tavanomaiset tuotantolaitokset ovat pystyneet tuottamaan tehotasapainon ylläpitoon tarvittavan joustavuuden, mutta sääriippuvaisilla tuotantomuodoilla se ei ole varteenotettava vaihtoehto.

Sen sijaan energiankulutuksen on alettava joustaa. Tässä diplomityössä esiteltävä ratkaisu on maailman ensimmäisiä mikroverkkoja, jossa taloteknisiä kuormia, kuten ilmanvaihtoa ja valaistusta, käytetään reaaliaikaisesti sähköverkon tehotasapainon säilyttämiseen. Työ on tehty tapaustutkimuksena kauppakeskukselle, jonka mikroverkon osiksi asennetaan myös aurinkosähköjärjestelmä sekä akusto, jonka koko on noin 1,6 MW ja 2,0 MWh.

Suomen kantaverkkoyhtiö Fingrid on luonut avoimet reservimarkkinat, jotka sallivat mikroverkon osallistua tehotasapainon ylläpitoon reservinä. Tässä diplomityössä on tutkittu kuinka kyseinen mikroverkko voisi osallistua reservinä tehotasapainon säilyttämiseen ja kuinka suuret hyödyt tästä voisivat olla. Lisäksi esitellään ne periaatteet, joilla mikroverkkoa voidaan operoida niin, etteivät olosuhteet sisällä muutu sietämättömiksi eivätkä rakennuksessa sisällä olevat ihmiset huomaa mitään.

Esitetty ratkaisu pystyy luomaan uusia tulonlähteitä kiinteistöjen omistajille ja mahdollistaa tarkemman energianhallinnan tulevaisuudessa. Potentiaalisten tulojen määrää on mallinnettu työssä.

Samalla mikroverkkoratkaisulla on erittäin suuri potentiaali olla halvempi vaihtoehto reservi- ja varavoimalaitoksille, jota muuten tarvittaisiin verkon tehotasapainon ylläpitoon. Yleistyessään kysyntäjoustoratkaisu mahdollistaisi huomattavat yhteiskunnalliset säästöt, kun ei tarvitsisi investoida kalliisiin voimaloihin joita käytetään vain kulutushuippujen aikoihin.

Avainsanat mikroverkko, tehoreservi, kysyntäjousto, kysynnän jousto, älykäs energiajärjestelmä, tehotasapaino, talotekniikka, kauppakeskus

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Sami Laakso

Contents

Abbreviations

aFRR	Automatic Frequency Restoration Reserve
CHP	Combined Heat and Power
DALI	Digital Addressable Lighting Interface
DR	Demand Response
DSM	Demand Side Management
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal operation
FERC	Federal Energy Regulatory Commission
FiT	Feed-in tariff
FRR-M	Manual Frequency Restoration Reserve
€/MW,h	Euros per Megawatt of an hour of availability
MEMS	Microgrid Energy Management System
OPEC	Organization of the Petroleum Exporting Countries
Ppm	Parts per million
SEDC	Smart Energy Demand Coalition
Wp	Watt-peak, peak power of a solar power plant in watts

1. Introduction

The electricity production portfolio in Finland is changing rapidly at the time. Building of renewable power production plants is strongly supported by the Finnish government and the European Union (EU). As the share of the renewable electricity is growing, the share of fossil fuel based production is decreasing. This causes challenges in the future: the weather-dependent electricity production can't adjust to the needs of uneven consumption the same way as the traditional production ways. That's why demand response (DR) will be needed all the time more and more in order to maintain the power balance in the grid. The electricity portfolio of Finland of the years 2011 and 2015 is presented in the table 1.1.

Table 1.1. Electricity production by source and the total consumption in Finland in 2011 and 2015. (Tilastokeskus 2017)

Electricity production type	Electricity production in 2015 (GWh)	Share of the total consumption in 2015 (%)	Electricity production in 2011 (GWh)	Share of the total consumption in 2011 (%)
Hydropower	16 584	20.1 %	12 278	14.6 %
Wind power	2 327	2.8 %	481	0.57 %
Solar power	10	0.012 %	5	0.006 %
Nuclear power	22 326	27.1 %	22 266	26,4 %
Condensing power	4 062	4.9 %	9 822	11.7 %
Combined heat and power	20 846	25.3 %	25 567	30.3 %
Total domestic production	66 155	80.2 %	70 420	83.6 %
Net imported electricity	16 337	19.8 %	13 851	16.4 %
Total consumption	82 492	100 %	84 271	100 %

Even though the electricity portfolio of Finland is changing rapidly, it's still quite versatile. It consists of large shares of hydro and nuclear power along with combined heat and power (CHP) and electricity imports. These are completed by smaller shares of e.g. wind and condensing power. The wind and solar power capacities are currently growing strongly and at the same time, the shares of combined heat and power (CHP) and condensing power are decreasing.

For example, the total wind power capacity in Finland has been 627 MW, 1005 MW and 1553 MW at the end of years 2014, 2015 and 2016, respectfully (Suomen tuulivoimayhdistys 2017). This means that during the previous years the growth of the capacity has been around 400...500 MW per year. The production capacity has been forecasted to grow up to 2170 MW by 2020 (ÅF-Consult Ltd 2016). With the experienced growth rate, it can be expected, that the forecasted capacity can well be achieved, most likely even exceeded.

Currently new wind power plants have been granted for a feed-in tariff (FiT) by the government for the first 12 years in operation (Motiva 2017). The feed-in tariff is paid on top of the market-price for area Finland (Elspot FIN). If the market price of electricity is negative, no FiT is paid; if the market price is less than 30 €/MWh, the FiT is 53,5 €; and the Elspot FIN being more than 30€/MWh, the FiT is the differential between the target price 83,5 €/MWh and the market price. Only 2500 MW of new capacity altogether will be accepted in the feed-in tariff system to limit the governmental risk on expenses. (Energiavirasto 2016)

Also the solar power production is growing strongly at the moment. It has roughly doubled between the years 2011 and 2015, but it still isn't a significant electricity production form in Finland. In 2015 the electricity production from solar power plants was 10 GWh, making altogether little less than 0.02 % of the whole Finnish electricity production. Including the net electricity imports, the share was narrowly more than 0.01% of the total electricity consumption. (Tilastokeskus 2016) Nevertheless, solar power has become more and more attractive way to produce electricity locally in Finland.

First of all, that is due to the fact that the price of solar panels has been decreasing heavily during the previous years (Finsolar 2017). Secondly, local small-scale production is tax free up to 800 MWh per year (Finlex 2017). Thirdly, the produced electricity doesn't need to be transmitted either long distances from the power plant to the end-user in the national electricity grid or locally in the distribution grid. That means no transmission fees are paid. The taxation and the transmission fees make roughly up to two thirds of the total electricity price for the end-consumers. The energy produced with small-scale solar power plants and consumed solely by the producer instead of selling it, has a significant saving potential for the energy users.

On top of all these, the solar power investments made by companies and communities can gain up to 25 % of support from the Finnish government (Tekes 2017). This has clearly been realized in the markets since the solar power production has doubled in 4 years from 5 GWh in 2011 to the total of 10 GWh produced in 2015 (Tilastokeskus 2017). Based on the presented facts, it can easily be predicted that the share of solar power will continue growing fast in the future too.

Besides the new renewables, also nuclear power capacity is growing. One new nuclear power plant is currently under construction and another one is in the licensing phase. The Olkiluoto 3 power plant is estimated to start the commercial electricity production during 2018, with the nominal output power of 1600 MW (Yleisradio 2016). The Hanhikivi 1 plant should start operating in 2024 and will have the power capacity of 1200 MW (Fennovoima 2017).

These plants will have the combined electric power of 2800 MW, which corresponds almost 20% of the maximum electricity power need in Finland. The existing nuclear power capacity in Finland is 2764 MW combined from two plants in Loviisa and two in Olkiluoto. The Loviisa plants have the licence to produce electricity until 2027-2030 and the two already existing reactors at the Olkiluoto power plant area have applied for the licence to continue until the year 2038 (Fortum 2017) (Teollisuuden Voima Oyj 2017). This means that at the end of the 2020's the nuclear power production will be roughly twice as much as nowadays, if all the plans come true.

However, the nuclear power has traditionally been supplying the base load power, since its regulation ability is significantly lower compared to many other electricity production forms such as hydropower, CHP and condensing power. In Finland the nuclear power plants are mostly still operated this way, but in Germany the electricity production of nuclear power has been forced to start adjusting their production based on the production of the renewable sources and the electricity consumption. In the figure 1.1 are presented the operating sequences of the nuclear power plants Olkiluoto 1 in Finland and Isar 2 in Germany in the year 2013.

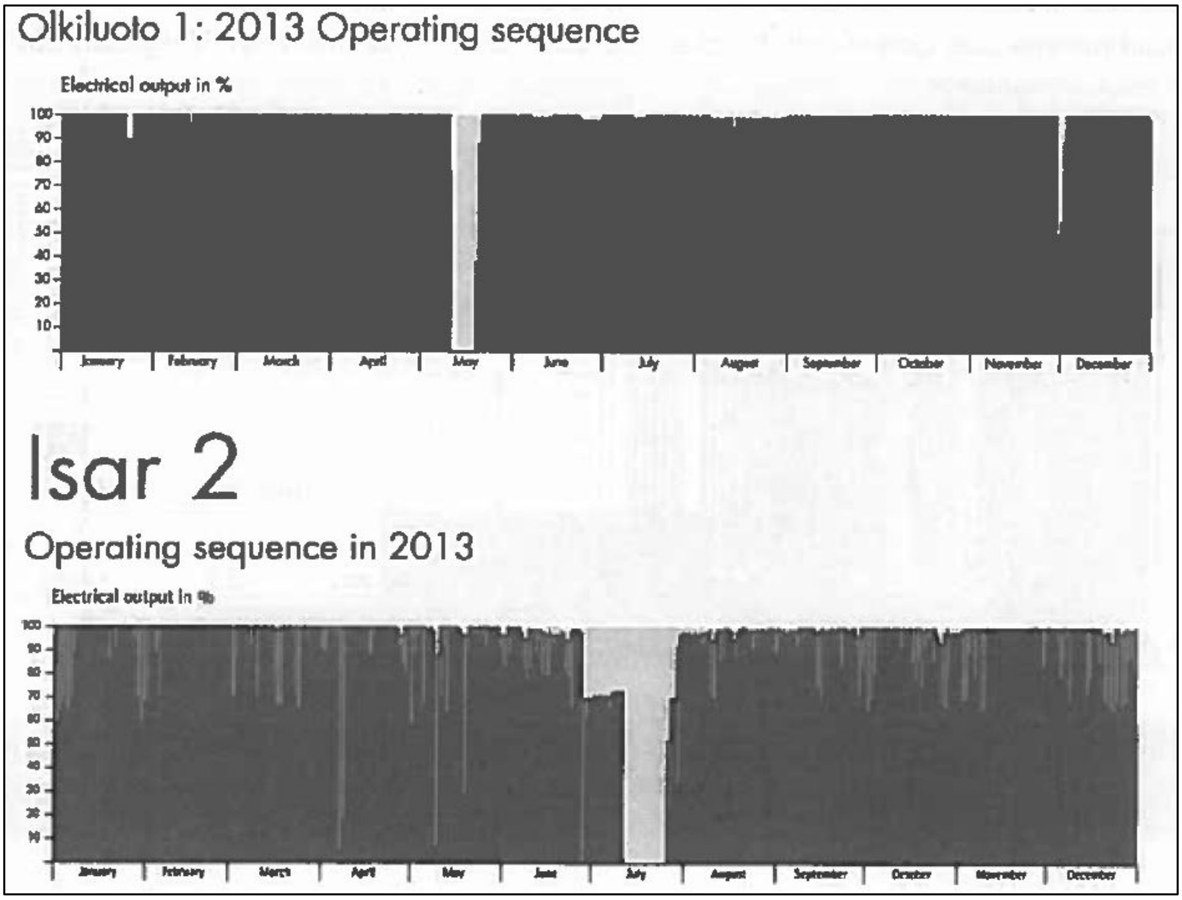


Figure 1.1. The operating sequences of nuclear power plants Olkiluoto 1, Finland, and Isar 2, Germany, in 2013. (Epple 2015)

The fragmented operating sequence that has occurred in Germany already since 2013, can also take place in Finland in the future, if the share of weather-dependent renewable energy production keeps on growing and the demand response won't become more popular. This would mean that the nuclear power plants are not operated in the optimal way, which can cause e.g. the equipment to wear faster than with the optimal electricity production cycle.

The suboptimal operation causes the increase in the maintenance costs and consequently higher electricity prices. Also, the total CO_2 emissions may increase at the same time, as the massive nuclear power plants cannot react to changes as fast as e.g. smaller and more agile gas turbines, which should be operated more than nowadays.

At the same time as the presented shares of inflexible production forms, such as nuclear power and new renewables are growing, the share of flexible production forms like hydropower, condensing power and combined power and heat (CHP) are staying roughly the same or getting smaller.

Hydropower not only produces 14…20 % of the consumed electricity in Finland, but it also provides the flexibility to maintain the power balance in the grid. (Tilastokeskus 2017) The hydropower can actually be handled as an energy storage, as the water reservoirs in some extent can be filled and emptied based on the demand. The limiting factors of the regulating capacity are the size of the water reservoirs, weather conditions and the size of the turbines. The hydropower capacity will stay approximately the same in the future, as there aren't really any more free streams left to be used for power production and the only real development in this sector could be improving the efficiency of the existing plants.

Instead, the shares of combined heat and power (CHP) and condensing power have been getting smaller during the last few years. In 2015 about 25.3 % of the electricity consumed in Finland was produced with CHP and 4.9 % with condensing power plants. In 2011 the shares were still 30.3 % and 11.7 % for the CHP and condensing power, respectively. In energy this means a drop of more than 4700 GWh for CHP and almost 5800 GWh for condensing power in the yearly electricity production. (Tilastokeskus 2017)

This drop has taken place even though CHP and condensing power have benefitted from the low fuel and carbon emission prices during the last few years. Organization of the Petroleum Exporting Countries (OPEC) estimates that the price of the oil fuels will increase at least back to the earlier levels (OPEC 2016).

During the year 2016 also the price of coal approximately doubled (Trading Economics 2017). Additionally, the European Union decreases the amount of CO2 emission allowances yearly by 1.74 %, which is also expected in its part to increase the price of electricity produced with fossil fuels (Kakkonen 2013). All the presented market signals could cause even faster decrease of the electricity produced with CHP and condensing power.

Finland is very dependent on the electricity imports. Before the year 2011 the share of net imports was for a longer time between 12.0 % and 14.9 %. But in 2011 the share grew to 16.7 % and since 2012 the share of net imports has been fluctuating between 18.7 % and 21.5 %. The lowest and highest volumes of net imports in the 2010's have been 10.5 TWh per year and 18.0 TWh per year in 2010 and 2014, respectively. (Tilastokeskus 2017) The imports are not only used to fill up the chronic gap between domestic production and consumption but also as a power reserve to maintain the power balance in the national grid (Fingrid 2017a).

For the Nordic countries, there must be a certain amount of reserve capacity maintained nationally so the country is still able to regulate the supply and demand even in an island operation mode, but under normal conditions up to one third of the frequency containment reserves (FCR) can be purchased from other Nordic countries. (Fingrid 2017o) In addition to this, Fingrid has also reserved 100 MW capacity from total of 1400 MW in 400 kV transmission line from Russia to Finland for reserve power purchases. To the opposite direction, 30 MW of the total of 350 MW has been reserved for reserve purchases. (Fingrid 2017f)

The security of supply for energy is a top priority on both the national level in Finland and on the EU level. Especially the dependency on the supply of the Russian energy is wanted to be significantly decreased than currently. Lund (2007) has shown that the energy security was one of the most important key factors already in 2002, when a licence was given by the Finnish parliament, to build the new Olkiluoto 3 nuclear power plant. In the same study, the renewable energy sources scored the same result as the nuclear power in the energy security. Meanwhile, the electricity and gas imports from Russia scored the lowest. (Lund 2007)

In order to help minimizing the dependency on Russia e.g. a ship terminal for liquefied natural gas (LNG) will be built to Finland (European Commission 2016). The security of supply of the gas is accompanied by a gas pipe connection to Estonia, which has been supported heavily by the European Commission with 187.5 million euro of the total budget of 250 million euro (Baltic Connector 2017).

As a conclusion, the new nuclear power plants and the recent growth of the share of renewables increase the security of supply and lower the need of electricity imports. This may unleash some transmission capacity for reserve use, but the priorities on security of supply don't favour this option, rather the reserve capacity should be located in Finland or at least in the Nord Pool region connected with suitable transmission capacity to Finland (Jäppinen and Kuivaniemi 2017).

The presented changes in the power production portfolio can create a problem to the flexibility of the power system and thus endanger the system stability in the future. Something should be done to maintain the current or even a higher level of the security of supply in the future too. One possible solution for system stability is demand response, which can be used to maintain the power balance. It can also help in increasing the security of supply in the future, if it becomes more common in the society (Motiva Oy & National Emergency Supply Agency 2016).

1.1. Demand Response

At the moment the power balance is maintained by adjusting the power production to correspond to the demand. In the future, demand response will be a great factor in the energy sector, not only as maintaining the power balance but also as providing the security of supply. This view is shared by many authorities and studies such as Fingrid (2017l), Motiva Oy & National Emergency Supply Agency (2016) and Smart Energy Demand Coalition (2015)

The term demand response is nowadays quite widely used and there are many different interpretations on the subject. Some of them are better than the others. For example, in the USA the Federal Energy Regulatory Commission (FERC) defines the demand response as follows:

> *"Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."*
>
> (Federal Energy Regulatory Commission 2017)

In this thesis, DR is understood in much wider sense than the presented definition of demand response by FERC and the traditional interpretation of demand side management (DSM). This is practically a must, since the concept is so new, that the traditional definitions are only partly suitable. Therefore in this thesis, demand response contains the following actions:

- Reserve response
- Load shifting

Of these two, the load shifting is closer to the traditional definition of the DSM and it's also a part of the definition of demand response by FERC. Here it is understood as a situation when the electricity consumption is shifted from expensive hours to the cheaper ones. This means that necessarily any energy won't be saved, but it is used when it is economically more sensible.

An example of the load shifting is, when a factory stops or slows down one non-crucial process for one or two peak-price hours and increases the production in the preceding and following hours around the expensive ones. This kind of operation doesn't save energy but it decreases the operating costs and perhaps can prevent turning on peak power plants, such as gas turbines. That way it can help reducing CO_2 emissions of the energy sector indirectly without any actual energy savings.

On the other hand, reserve response is something completely different. The production and consumption of electricity are almost never exactly the same, and this causes the frequency of the grid to change all the time. The reserves are used to balance the demand and the supply. The term reserve response is used for the actions that are made continuously to maintain the power balance.

The reserve response actions can be made either automatically or on demand, depending on the reserve market rules. The definition given by FERC contains only the situations when the electricity consumption is lowered, "when the system reliability is jeopardized". In this thesis, the reserve response contains also the actions that increase consumption and the actions made under normal operating conditions to maintain the power balance.

In other words, the greatest difference between the reserve response and load shifting is that the load shifting can be planned e.g. on the previous day based on the hourly prices of electricity whereas for the reserve response the power capacity has to be reserved for the offered times and the actions take place when needed.

It's possible, that sometimes the reserve response actions aren't needed at all even though the reserve capacity would have been offered, but it still has to be available, just in case. This means that the reserve response is a reactive action taking place in real-time according to the occurring situation, not a proactive nor a preventive action like load shifting and traditional DSM.

According to Smart Energy Demand Coalition (SEDC), the energy system of Finland is one of the most developed and open ones in Europe when regarding the demand response aspects. Other highly developed systems are in France, in Switzerland, in Belgium and in the UK. Other countries have still either legislative, market or other restrictions for demand response. This is the current situation, even though DR has been acknowledged politically on the European level as an important enabler of the security of supply, integration of renewables and consumer empowerment. It has been noted e.g. in the Energy Efficiency Directive. (Smart Energy Demand Coalition 2015)

1.2. Scope of the Thesis

This thesis is written as a case study about a smart building concept developed by Siemens Osakeyhtiö (later as Siemens). The concept will be implemented in the shopping center Sello for the first time in the world. The revolutionary concept has already in a short time gained attention and created some buzz around the topic, like the news in Talouselämä

(2017), in Tekniikka & talous (2017), and on MTV (2017) show. Also the government and the owners of Sello clearly believe that the project can have a great impact on the Finnish energy system. (Ministry of Economic Affairs and Employment 2017b) (Realprojekti Oy 2017) (Keva 2017)

In the smart building concept a microgrid is created inside a building. The microgrid solution allows controlling the installed building technology as a flexible power reserve, that can adjust to the sudden changes taking place in the electricity grid. This thesis focuses mostly on the case implementation for the shopping center Sello and other possibilities and prospects are considered when applicable.

The research questions of this thesis are:

- What kind of aspects have to be taken into consideration when creating a microgrid from building technology units inside a single building block?
- How should a microgrid be operated, so that the indoor conditions won't become intolerable?
- How great is the possible income that can be gained from the microgrid solution?

1.3. Structure of the Thesis

In this thesis, it is mostly focused on creating and operating a microgrid, that can be a part of the frequency containment reserves. The thesis is made as a case study based on the project, that will be conducted in the shopping mall Sello. The project will be the first application of its kind inside the single building in Finland. It is very likely that this is also the first one in Europe and possibly even the first one in the world.

Firstly in this thesis, a short review of the current status and the near future prospects of the energy system in Finland are represented as a background overview. Then in the second chapter, the electricity and reserve markets are introduced shortly in order to make the full context clear for the reader.

The third chapter focuses on the different parts and systems of a microgrid. The qualities and quantities of each system are introduced and their restrictions in operation are taken into account. The fourth chapter explains how the microgrid could be operated as a reserve. First the required IT-connections with Fingrid are showcased. This is an important feature in order to participate the reserve markets. Then possible operational models and actions of the microgrid are introduced through a few simple examples.

In the fifth chapter it's shown how the possible income of the microgrid solution is calculated, what kind of assumptions and preconditions have been set and argued how they have been chosen. In the chapter six, the results from the calculations introduced in the previous chapter are explained.

The more detailed analysis of the calculations and the future potential of the microgrid is done in the chapter seven. Also the potential risks and other limiting factors are elaborated in this chapter. The thesis in completed with the eighth chapter, where the overall conclusions and future prospects of the microgrid solution are evaluated.

2. Electricity and Reserve Markets

In this chapter different electricity marketplaces in Finland are introduced. The microgrid, that will be created for the shopping center Sello, won't participate in all the markets. All the markets are still introduced to show, how extensive the electricity markets are, how they work together and how the changes in the electricity system may affect them in the future.

The main direct markets for the solution in Sello are FCR-N and FCR-D reserve markets. These markets have minimum power capacity sizes low enough for the project to participate, whereas the other reserve markets have at least the minimum power capacity requirement of 5 MW, which is too high requirement for this project.

The microgrid can also take part indirectly to the Elspot market through the electricity company, when the electricity price is connected to the Elspot price. The electricity price isn't necessarily always bound with the Elspot since the prices of electricity in Finland have traditionally been constant throughout a year, no matter how the prices fluctuate in the markets. If the electricity price is bound with the Elspot, the price differences of consecutive hours can be utilized for the benefit of the microgrid owner.

2.1. Nord Pool

Nord Pool is the leading energy marketplace in both day-ahead and intraday markets in nine countries in Europe. In total, 505 TWh of electricity was traded during 2016 in different markets of Nord Pool. It is owned by national transmission operators (TSO) of the Nordic and Baltic. The owners of Nord Pool are:

- Fingrid (Finland)
- Statnett SF (Norway)
- Energinet.dk (Denmark)
- Svenska Kraftnät (Sweden)
- Elering (Estonia)
- Augstsprieguma tikls AS (AST) (Latvia)
- Litgrid (Lithuania)

Besides to the home countries of the company owners, Nord Pool is also operating in the United Kingdom and Germany. (Nord Pool 2017a)

2.1.1. Day-ahead Market - Elspot

The Elspot market is the leading electricity trade market in Nordic and Baltic countries. Elspot is an energy-only market where solely produced electrical energy is sold and bought. It is a day-ahead market where the offers for each hour of the next day are made on the previous day by 12 o'clock central European time (CET). (Nord Pool 2017f)

All the sell and buy offers are then organized into ascending and descending order, respectively. This is also known as the Merit order. The intersection of these curves determines then the spot price for each hour. This is known as the system price. Since there are still limitations in the transmission capacities inside and between countries, different spot prices are created for different areas with the same principle as the system price (Nord Pool 2017f).

The spot prices in the different areas can vary greatly from the system price, depending on the transmission capacity between price areas as well as production and consumption inside the areas. Therefore, the system price is practically a theoretical value that takes place in every area only, when the current transmission capacity is sufficient to meet all the needs, or all the transmission constraints between the separate areas would have been removed.

For example, the yearly average spot price in Finland in the years 2010-2016 has ranged from 2.25 to 8.68 €/MWh higher than the system price. At the same time, the Norwegian areas Oslo, Kristiansand and Bergen have had somewhat lower area prices than the system price has been. (Nord Pool 2017b) This is due to the fact that the transmission capacities to other areas have been too small for the market to operate efficiently and transmit the cheaper production to areas with higher spot price.

The load shifting aspect of DR produces benefits from the variation of spot prices during a single day, when the electricity consumption can be increased on those hours when the price is low and decreased when the price is high. Likewise the price differences can be used to charge a battery with cheap electricity and discharge when the price is high. These aspects are the main functionalities connected to the spot-prices, that can reasonably be used in the microgrid solution, but still their potential significance is relatively small in the big picture. That's why this aspect has been left outside of the scope of this thesis.

2.1.2. Intraday Market - Elbas

On the Nord Pool markets, most of the electricity is traded on the day-ahead markets. This is based on the fact that the production and consumption forecasts are relatively accurate. But still there is a need for trading closer to the delivery, since the production forecasts are never completely accurate and naturally there can always occur events that can’t be foreseen. Such events may be for example a power plant stops operating or the winds are much stronger than expected on the previous day causing significantly more wind power production. Also, the electricity consumption patterns cannot be forecasted exactly spot on. (Nord Pool 2017d)

Nord Pool publishes the capacities available for intraday trading at 14.00 CET and the trading can be executed until one hour before delivery. In the contrary to the day-ahead market, the trading is not based on the one collective price that all the sellers get and buyers pay, but the trades are accepted individually. This means that the prices for certain time slot may vary greatly before the delivery and it’s depending on the timing of the buyers and sellers when they can get the best price on the markets. (Nord Pool 2017d)

The trading can be done every day of the year and around the clock. It is possible to have 15 minute, 30 minute hourly and block offers in the intraday market. The trading offers are given in an online platform provided by Nord Pool. (Nord Pool 2017e) This solution provides normally flexibility enough for the market players to balance their energy balances for each hour.

For the project in the shopping center Sello, the Elbas market is not relevant since Nord Pool charges fees for participating the markets. For example, an annual fee of 10.800 € and an energy fee of 0.11 €/MWh must be paid for participation to the Elbas market only. An annual fee of 18.000 € allows the participation to the Elspot market too, where an energy fee of 0.04 €/MWh is charged. (Nord Pool 2017c) The participation fees make it less profitable for the project to take part in the Elbas market instead of reserve markets. Therefore the Elbas market is left out of the calculations and is here introduced only as a potential option in the future.

2.2. Fingrid

The backbone of the electricity network is that the production and consumption are constantly in balance. Since the consumption cannot be forecasted completely accurately for every moment in the Elspot and Elbas markets, the system must have some flexibility to withstand normal volatility and even great and sudden changes in the system.

Normal volatility is caused by the discontinuous behaviour actions in the grid, like cyclical industrial processes or when people come home in the evening and turn on the home entertainment equipment and saunas as well as when they start cooking dinner at the same time. Sudden changes in the system are for example an operational failure in a big power plant or a start or a shutdown of an energy intensive industrial process. For these instances there must always be some flexible capacity available that can react when these unexpected changes happen.

Therefore, the Nordic Transmission System Operators (TSOs) in Finland Sweden, Norway and East-Denmark have agreed on the reserve maintenance obligations for the Nordic transmission area. The reserves are divided into four groups based on their purpose and requirements:

- Frequency Containment Reserve for Normal operation (FCR-N)
- Frequency Containment Reserve for Disturbances (FCR-D)
- Automatic Frequency Restoration Reserve (aFRR)
- Manual Frequency Restoration Reserve (FRR-M)

In Finland, the FRR-M contains both the Regulating Power Market as well as the reserve power plants leased and owned by Fingrid (Fingrid 2017j). The reserve power plants are fully dedicated only to the FRR-M operations in serious power shortage situations and they cannot take part to the commercial electricity production. (Fingrid 2017m)

For this reason, from the FRR-M reserves only the Regulating Power Market is taken into account in this thesis, since only those markets are open for participation to all players on the field. It is therefore commercially significantly more interesting for the current project as a future prospect. At the moment the minimum power capacity is 5 MW, which is too high for the shopping mall to enter the market. (Fingrid 2017j) Possibly the minimum power restriction will be lower in the future, or Sello will have capacity enough, so the participation for the market is possible.

The total amount of each reserve type in Nordic countries and the country-specific obligations for Finland are represented in the table 2.1. (Fingrid 2017p) Since the project is executed in Finland, the Nordic reserve operation principles are only introduced as a background information, and when directly connected to the project or otherwise applicable.

Table 2.1. The combined reserve obligations of the Nordic countries and the share of the reserve obligations of Finland. (Fingrid 2017p) (Fingrid 2017j) (Fingrid 2017g)

Reserve type	Amount in the Nordic countries	Amount in Finland	Minimum Power
Frequency Containment Reserve for Normal operation (FCR-N)	600 MW	140 MW	0.1 MW
Frequency Containment Reserve for Disturbances (FCR-D)	1200 MW	220...265 MW	1 MW
Automatic Frequency Restoration Reserve (aFRR)	300 MW	70 MW	5 MW
Manual Frequency Restoration Reserve (FRR-M)	Area-specific amount to cover the dimensioning fault or the area	880...1100 MW	5 MW if electric ordering available, otherwise 10 MW

In the following chapters these reserve types are introduced more detailed from the Finnish perspective and how Fingrid has created markets for individual actors to take part in balancing the electric system. The Fingrid markets are open to different players, no matter if they are electricity producers or consumers. It is enough for the participation that the offered capacity fulfils the minimum requirements and market rules of each marketplace and that the actor has signed a contract with Fingrid for participation. In the reserve markets the flexible consumption can stabilize the national grid. This flexibility is rewarded with a compensation by Fingrid.

The offset from the balance point can be noticed in the changes of the frequency in the network. The frequency drops when the consumption is greater than the production and analogously increases in the opposite situation. The aim is to keep the frequency within the predetermined boundaries. Adjusting the production or demand response is needed to maintain the balance. The increase of both, the weather-dependent renewable energy production and the nuclear power, that is usually operated with a constant power output, requires more consumption that is capable to response to the power supply.

On the seminar “Reserve days“ (Finn: Reservipäivät) on the 17th to the 18th of May 2017, Fingrid announced that new FCR regulations have been drafted on the Nordic level. The new rules can cause some of the current reserves, such as hydropower plants, not to qualify as a FCR reserve in the future if the plants aren’t updated to fulfil the new requirements. The changes and exits of current reserves could open markets for new reserve providers with new solutions. At the moment of writing this thesis, it has been requested that the market players should give their comments on the new market rules. After this, the rules will be reviewed by the Nordic TSOs and they should come in force during the next years. (Fingrid 2017q) Since the future rules are still in the commenting phase and not completely clear, they won’t be taken into account in this thesis and only the currently effective rules are considered to be valid.

2.2.1. Frequency Containment Reserve for Normal Operation

The electricity production and consumption have to be in balance all the time. The difference between production and consumption can be seen from the frequency of the grid. If the consumption is higher than the production, the frequency drops. Analogously, if the consumption is smaller than the production, the frequency rises.

The nominal frequency of the grid is 50.00 Hz. In the normal conditions the frequency is allowed to fluctuate between 49.90 Hz and 50.10 Hz. To balance the consumption and production so that the frequency stays in this range, the Frequency Containment Reserve for Normal operation (FCR-N) is used. The FCR-N reserves adjust automatically their power according to the frequency so that it would restore back to 50.00 Hz. This means that the reserve has to be able to regulate both upwards and downwards all the time when it's active.

On the Nordic level a total of 600 MW of FCR-N reserve is maintained all the time and the country-specific shares are divided every year based on the total yearly consumption of each nation. The share of Fingrid is 140 MW. (Fingrid 2017p)

The minimum size of a single FCR-N reserve is 100 kW. This means that the system operating as a reserve has to be able to regulate the 100 kW power both upwards and downwards. The system has to be activated fully within three minutes when a frequency changes ± 0.10 Hz as a single step. The second option is that the system adjusts almost linearly depending on the frequency. (Fingrid 2017c)

The participation to the FCR-N reserves takes place either through yearly or hourly markets or both. For the yearly markets of the next year, an offering round is organized around September and October. During the process, the applicants place their offers including the reserve size and the price of the reserve. Fingrid then arranges the offers in an ascending price order. (Fingrid 2017g)

After that, the offers are approved starting from the cheapest ones and finally it's decided which offer is the last one to be accepted to the yearly markets. All the accepted offers will subsequently get the same price for their reserves as the highest accepted price. (Fingrid 2017g) During the year, Fingrid will buy all the maintained reserve from the yearly markets as long as it is offered according to the rules (Fingrid 2017w). This ensures the income for reserve providers, even though the price per offered reserve level may be lower than on the hourly markets.

On the hourly markets, the offers for each hour of the next day have to be made daily by 6.30 pm. Similarly, as on the yearly markets, the offers are arranged in an ascending price order and all the accepted offers will be paid by the highest accepted offer. If a reserve provider is taking part in the yearly market too, the share of the yearly market has to be offered and maintained fully, before one can enter the hourly markets. (Fingrid 2017k)

2.2.2. Frequency Containment Reserve for Disturbances

On the Nordic level, the size of the Frequency Containment Reserve for Disturbances (FCR-D) must be maintained great enough so that the frequency drop of the grid would be less than 0.50 Hz, if the biggest individual fault should occur. The grid has a natural self-regulation capacity of 200 MW, which is deducted from the size of the biggest individual fault. The biggest individual fault can be for example a disconnection of one massive power plant. This approach is called as N-1 principle. In normal conditions around 1200 MW FCR-D reserve is maintained. The maintained amount of FCR-D capacity is decided weekly. The share of Finland of the FCR-D capacity is around 220...265 MW. (Fingrid 2017p)

In the future, when the Olkiluoto 3 nuclear power plant will start the normal operation, the FCR-D capacity must be increased according to the current conditions since the plant has the nominal output power of 1600 MW. It would increase the total FCR-D capacity to 1400 MW, assuming the current self-regulation capacity of 200 MW and currently valid rules. Therefore, the share of Finland would increase close to 300 MW, or maybe even higher, since the power plant is located inside the territory of Fingrid and other TSOs may require additional reserves locally.

For the FCR-D there are also yearly and hourly markets. The participation to the markets and the market rules in general are the same as on the corresponding FCR-N markets. However, the technical requirements are different. The reserve are activated when the frequency drops below 49.90 Hz and it should adjust the reserve power almost linearly down to 49.50 Hz. Half of the reserve should be activated within five seconds and the reserve should be activated fully within 30 seconds. The reserve can be return back to the initial state, when the frequency has stayed at least for three minutes above 49.90 Hz. (Fingrid 2017c)

The minimum size of a reserve participating the FCR-D markets is 1 MW and the offers have to be made with an accuracy of 0.1 MW (Fingrid 2017c). The minimum offer makes it impossible for many actors to participate to markets alone. However, in the FCR-D markets it’s possible to aggregate reserve resources from different reserve providers, on the contrary to the FCR-N and aFRR markets where the aggregation is completely forbidden and the FRR-M market where the aggregation is only conditionally allowed. (Fingrid 2017s) This allows multiple actors to join together and offer their combined capacity to the FCR-D markets as a single asset. The possibility for aggregation in the other markets is assumed to take place gradually and by one market at the time during the coming years, but at the moment there isn’t still a schedule available for this (Fingrid 2017q).

2.2.3. Balancing Power Market

The balancing power market is a part of the FRR-M reserves, as stated earlier in the chapter 2.2 (Fingrid 2017j) It is used to control the prolonged disturbances in the grid. The balancing power is turned on by request and it replaces the activated FCR-N and FCR-D resources so that those can be used again for further regulation of the normal conditions and disturbances.

All the actors, who can implement a power change of 10 MW within 15 minutes, can participate the balancing power market. The power change can be either up- or down-regulation. The bids can consist of both power production and consumption units. (Fingrid

2017d) Even thought the minimum regulating capacity in the balancing power market is too high for the case Sello, it will introduced more detailed in this thesis. Since it is maybe the most important balancing market in Finland, it can already give an indication of the future development of the other markets too.

The binding bids for the market must be submitted at latest 45 minutes before the specific hour. A bid must contain the regulating power, the price of energy, the area, where the unit is located and the name of the resource. Also the general information of the unit type, production or consumption unit, must be included. (Fingrid 2017d)

The up–regulation offer consists of increase of power production or decrease of consumption. Basically, the owner of the resource is selling electricity to Fingrid. Fingrid pays the same up-regulating price to all the electricity sellers from which Fingrid has bought during the specific hour. The up-regulating price is the price of the most expensive up-regulating offer that has been used during the hour. The minimum price of the up-regulation is the Nord Pool's Finnish spot price of the same hour. (Fingrid 2017d)

On the contrary, the down–regulation offers can consist of decrease of power production or increase of consumption. Basically, the owner of the resource is buying electricity from Fingrid. The same down-regulation price is paid by all the electricity buyers to whom Fingrid has sold electricity during that hour. The down-regulating price is the price of the cheapest down-regulating offer that has been used during the hour. The maximum price of the down-regulation is the Nord Pool's Finnish spot price of the same hour. (Fingrid 2017d)

The price level on the balancing power market is normally relatively close to the Nord Pool's Finnish spot price. However, sometimes they can differ even greatly from that. This kind of peaks take place usually, when something surprising or unexpected events happen. Such events may be for example problems in the power production or transmission. It can also be expected that the increase of weather-dependent power production can have a great affect on the prices of the balancing power market.

For example, in the night between the 6th and 7th of May 2017, the down-regulating power price went first down to -500 € for two hours and then down to -1000 € for four hours. In down-regulation producers decrease their production and consumers increase their consumption, so they are buying electricity from Fingrid. In other words, there was more electricity production than the consumption during those hours. Since the price was negative, Fingrid was basically paying to consumers for consuming more electricity in these hours than they would have needed normally.

The explanation Fingrid gave about the event was that there were constraints in the electricity transmission capacity caused by network tests made in the Swedish electricity grid. Also the electricity consumption was lower than the balance providers had estimated. (Fingrid 2017n) One thing was almost totally ignored by Fingrid: the wind power production peaked significantly compared to the forecasts in these exact hours as the negative prices occurred. (Taloussanomat 2017) The wind power forecasts and actual production along with the down-regulating prices and amounts for 6th and 7th of May are represented in the figure 2.1.

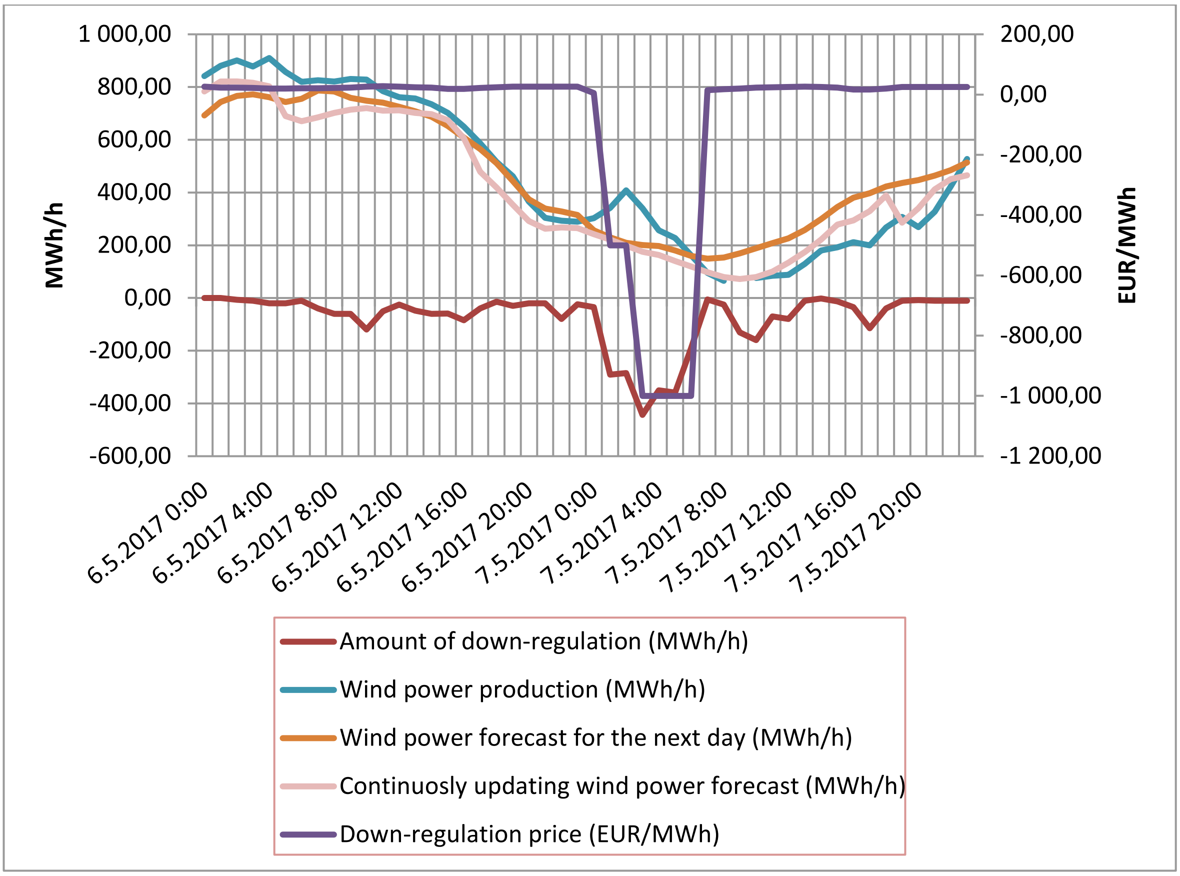


Figure 2.1 Price and volume of down-regulating power and forecasted and actual wind power production on the 6th to 7th of May 2017. (Fingrid 2017t) (Fingrid 2017u) (Fingrid 2017e)

Even though it cannot be claimed that the wind power alone caused the negative prices, it can partially be held responsible for them. The greatest difference between the forecast and the actual production was 210 MWh, when the amount of down-regulation was 285 MWh/h. This makes up to 74 % of the total down-regulation of the specific hour. The share of the additional wind production of the down-regulation was at least 22 % over the six-hour period. (Fingrid 2017u) The unexpected excess of wind power production has therefore made the situation worse than it would have been otherwise.

The negative price hours with the down-regulating amounts, the difference between the wind power forecast and actual production and the share of the not-forecasted wind power of the down-regulation are represented on the table 2.2. As it can be seen on the table, the unexpected, additional wind power had a significant share of the down-regulation volume on all hours.

Table 2.2 Price and volume of down-regulating power, the difference of the forecasted and actual wind power production and its share of the total down-regulation power on the 6th to 7th of May 2017. (Fingrid 2017u) (Fingrid 2017e) (Fingrid 2017t)

Time (UTC)	Down-regulation price (EUR/MWh)	Volume of down-regulation (MWh/h)	Difference between the wind power production and continuously updated forecast (MWh)	The share of the additional wind power of the total down-regulation power (%)
6.5.2017 22:00	-500,00	290,42	119,69	41 %
6.5.2017 23:00	-500,00	285,00	210,11	74 %
7.5.2017 0:00	-1 000,00	443,33	165,20	37 %
7.5.2017 1:00	-1 000,00	350,00	94,44	27 %
7.5.2017 2:00	-1 000,00	358,33	86,84	24 %
7.5.2017 3:00	-1 000,00	189,67	42,56	22 %

The lack of cheaply flexible power production, that has disappeared from the markets during the last years, and demand response could have prevented the extremely negative prices. For these six hours of down-regulation Fingrid had to pay altogether over 1.63 million Euros to the regulation providers instead of normally gaining money for selling the excess electricity.

In the year 2016 the average down-regulating price was 28.18 €/MWh and in 2017 it had been 29.19 €/MWh before the 7th May. (Fingrid 2017e) The average volumes for the same time ranges were 19.8 MWh/h and 25.3 MWh/h, respectively (Fingrid 2017u). If it is assumed the down-regulation price of 28 €/MWh and the occurred volumes of down-regulation, Fingrid would have gained over 50.000 € for these hours instead of losing money. With a volume of 24 MWh/h, which is closer to the historical averages, Fingrid would still have gained over 4.000 €.

The presented negative prices are a great cost for Fingrid and they are relatively new phenomenon, that has started to occur only since the share of the renewable energy production has begun to increase. The negative prices are still needed, because only the they can encourage the electricity producers to decrease their production when the consumption is too low in relation to production. With the positive prices the producers would have to pay to Fingrid for decreasing their production, which wouldn't make any sense to them in the most cases. Therefore, the negative prices can be seen as the "new normal" but nevertheless the extremely negative prices are still a great cost to Fingrid.

Still, it can be said with a great certainty, that the main target of the down-regulation should be the electricity consumers. For them it is much more beneficial than for the producers: they get cheaper electricity than they would get from the spot markets which helps improving their competiveness in their own markets. Let’s take a company that has power flexible processes as an example. For the company the negative prices are actually a double benefit. First the company gets paid for using more electricity for increasing the production temporarily. Then the company can sell the products it has produced during those hours either with the normal price or even with a lower price without losing their profit margins. This gives them a vantage in the comparison with their competitors.

2.2.4. Automatic Frequency Restoration Reserve

Automatic Frequency Restoration Reserve (aFRR) was introduced in 2013 as a new reserve type. The main function of it is to restore the frequency back to the target frequency. The target frequency is usually 50.00 Hz, but it can also be different, if there should be a need to restore the time deviation. The acquisition of reserves is done with hourly markets only. (Fingrid 2016a) At the moment of writing this thesis, the aFRR is still in a testing phase and it’s activated only in certain hours. It’s hoped to replace some of the FCR-N capacity in the future, but still not completely. (Fingrid 2017r) As the future role of the aFRR in the electricity markets is currently rather unclear, it is only introduced shortly in this thesis.

Fingrid notifies the reserve providers well before in which hours the aFRR will be activated. The reserve providers can then offer their power capacity in both up- and down-regulation for the corresponding hours. The minimum power capacity to be offered is 5 MW. The up- and down-regulation offers are put in the price order separately and Fingrid confirms the accepted trades for the next day by 6.05 pm EET. The reserve providers get paid by the price of they have offered, not with the principle “same price for all”, like in the regulating power market. (Fingrid 2016b)

aFFR is activated based on the frequency deviation of the Nordic synchronous area. The activation of reserves is done with an activation signal. The activation signal is sent from the operation center of Statnett SF (Norway) to all of the Nordic TSOs. The TSOs in their turn then forward the activation signal to the reserve providers. (Fingrid 2016a)

Fingrid sends the activation signal every 10 seconds to the reserve providers. The signal is negative, if the activation is down-regulation and positive, if it’s up-regulation. The signal is sent to the reserve providers in Finland in the relation to the trades made in the hourly markets. The maintained reserve can contain multiple power units. Depending on the qualities of the power production reserve, the signal can be filtered or unfiltered. Filtered signal is usually used for hydropower plants and the unfiltered for others. For the consumption units, the signal type is decided every time separately. (Fingrid 2016a)

According to the aFRR contract, Fingrid is not responsible of the damages caused by an incorrect activation signal. (Fingrid 2016b) This is in a way understandable as Fingrid only shares the original signal from Statnett to the reserve providers, but it’s still possible that the original signal has been right but the signal sent by Fingrid isn’t. Surely the probability of a faulty signal is small, but it still exists.

That means that the reserve provider should still check the incoming signals to prevent the possible damages to the equipment caused by faulty signals. It causes a dilemma when the power regulation should be automatic but the messages still should be authenticated first to be correct. For some units it can cause even the reserve response actions to slow down that much, that the reserve can’t fulfil the requirements anymore. Therefore before the testing phase of the aFRR ends and the normal operation starts, the dilemma should be considered carefully, as it can halt the decision making process of some actors for taking part to the market.

3. Creating a Microgrid

The shopping mall Sello has a long partnership with Siemens in energy management and efficiency. As examples of the energy efficiency improvements, the ventilation is controlled based on the needs, instead of pre-scheduled programs, and the melting of snow in the outdoor areas is optimized based on the weather forecasts. During the last five years, the need of heating in Sello has dropped by 20 % and the electricity consumption by 10 %. (Sello 2017)

The long partnership has resulted into a situation that Sello was the first shopping center in Europe to gain platinum certificate of LEED for Existing Buildings in 2015. In 2010 Sello had already gained the LEED gold certificate. The LEED certificate takes into account not only the energy efficiency, but also the accessibility of the premises by public transportation, building maintenance and water usage. LEED certificates are awarded by U.S. Green Building Council. (Sello 2017)

The interest in the sustainable and efficient use of energy and other resources has required much more detailed metering in the premises than normally is used. The metering data is automatically transferred in digital format to be the analyzed by energy experts of Siemens. This means that the during the past years a lot of historical data has been accumulated, so that the use and the behaviour in the premises is well known to the date. This makes it possible to create quite accurate predictions for the upcoming hours and days based on the historical data.

In addition to the measurement data collected from the various equipment inside the shopping center Sello, also weather data is already taken into account. As an example, first an automatic system detects if there is snow on the ground. Then weather forecasts provided by a third party and local temperature measurements give the signals, when it’s the optimal time to melt the snow around the building. Possibly there isn’t even a need to turn on the heating at all, since soon enough the outdoor temperature will rise high enough to melt the snow during the day.

The current state of automation allows this project to take place with much lower investment costs than without the metering expanded earlier. The existing historical data and the experience in combining these with other data, like the weather forecast data, play a great role in reducing the operational costs.

In the project the microgrid is created consisting of the following systems:

- Ventilation
- Battery storage
- Solar power plant
- Lighting
- Outdoor ground heating

Some of the microgrid parts are completely new, some require new components or connections and some get only a software updates without any changes to the actual hardware. The microgrid may be expanded in the future when more individual systems with demand respond capability are recognized and they are interesting enough for the microgrid connection or if, for example, some tenants gain an interest to join the smart grid in the building. Each presented microgrid system is elaborated more detailed in the following chapters including their benefits and challenges.

3.1. Ventilation

The ventilation is a crucial part of the indoor conditions. It makes sure that there is enough fresh air in the building and provides heating and cooling when needed. Depending on the situation, either one of these parameters can be the limiting factor. In some spaces, the fresh air can be a more crucial element than the temperature, as the CO_2 concentration in the air may change much faster than the temperature. In other spaces the situation can be the opposite.

Luoma (2015) has shown that the CO_2 concentration can easily rise over 900 ppm in 15 minutes in a classroom environment, if the ventilation is turned off completely. Even the concentrations over 1200 ppm are not exceptional. If the ventilation was only dropped to 40...50 % of the normal level for 15 minutes, the changes in the CO_2 concentration were significantly smaller by staying mainly under 900 ppm. (Luoma 2015)

When the ventilation is not on, a building can be handled as an “oxygen storage”. The storage is slowly emptying, when the people inside the building are breathing. As the density of people per square and cubic metre is usually much higher in a classroom than in a shopping center, it can be said with a great certainty that the ventilation can be used as a reserve for at least 15 minutes.

Also the doors and windows of a classrooms are usually closed, but the doors of a shopping center are all the time opening as people go in and out. This would provide some excess air exchange between the indoors and outdoors, when the ventilation is turned down. Some ventilation units, such as the ones in the kitchens, aren’t used as a reserve, so they will still be providing some ventilation even during the reserve responses.

It should be noted here, that the ventilation doesn’t have to be shut down completely. Instead the lower limit can be determined to be e.g. at 15 % of the maximum power. Naturally, the maximum reserve response time of each unit and space should be tested before offering the power capacity of the ventilation to Fingrid.

Manninen (2017) in turn has stated that lowering the power of the ventilation for one hour in a shopping center environment doesn’t result in too high concentrations of CO_2. In the modelled situation the maximum concentration of CO_2 was 900 ppm tops, which is at the satisfactory level according to the Finnish standards, but the indoor temperature increased more than desired. (Manninen 2017) This would suggest that the CO_2 concentration isn't usually the most critical limiting factor for demand response in a shopping center; rather it is the indoor temperature.

The total power capacity of the ventilation in the shopping center Sello is around 900 kW based on what has been found in the project preparation phase. This means that there is approximately 450 kW up-and-down regulating capacity in ventilation system at its best. The minimum offer sizes on the FRC-N and FRC-D markets are 100 kW and 1 MW, respectively (Fingrid 2017g). Therefore this capacity on average is big enough alone to be offered to the FCR-N markets, but too small for the FCR-D markets.

The ventilation system of shopping center Sello consists of 98 individual machines. All the air handling units along with other microgrid units are listed in the appendix D. At the moment they are controlled based on the needs in the spaces, mainly depending on the CO2 levels and temperatures. This current way of controlling won't be removed, but the demand response dimension will be added on top of that.

80 % of the air handling units in the shopping center Sello have a control with the percentage of the dimensioning pressure. In this way of control, the wanted percentage is given as the pre-set value to the system and the automation adjusts the unit to the right speed. An example of the power curve of a such system has been illustrated in the figure 4.3.

The current rules for the FCR-N reserve markets require that the participating reserve must be able to react within three minutes after a single-step frequency change of 0.10 Hz. In the field tests made by Siemens, an individual ventilation machine was able to change the power input within few seconds after a command was made remotely through the building automation system. The reaction time restrictions are therefore not a problem for operating the ventilation as a reserve for FCR-N markets.

The ventilation system can therefore easily be used for the FCR-N purposes without a fear of not fulfilling the market requirements for the adjustments. The biggest risk are poor indoor conditions, that don't pass the indoor climate standards if the demand response continues too long. This may cause people inside the building to start to feel nauseous and the reputation of the shopping center could be damaged. In the long run the customers may start to disappear after a while causing big losses to the shopping center. This kind of event should never occur and there must be always an option to turn the demand response off, if needed.

It should be noted though that ending the reserve actions during the operating hour is a breach of the yearly and hourly agreements for FCR markets that must be signed by the reserve holder and Fingrid. In the agreement the penalties for non-provided capacity are also defined. In the worst case, neglecting of the reserve maintenance can even cause the termination of the contract. (Fingrid 2017k) (Fingrid 2017w) Therefore, it should be always ensured that the offered capacity can be provided fully without problems, discomfort or health hazards to the people inside the building. Some solutions for avoiding and minimizing these risks are presented under the chapter 4.2.

3.2. Battery Storage

Battery storage (SieStorage) is provided by Siemens including the battery control units. The battery is based on the lithium ion technology. The output power of the battery in the shopping center Sello will be around 1.6 MW and the total energy capacity approximately 2.0 MWh.

In Finland, one SieStorage unit has already been installed in Viikki Environment House (Finn. Ympäristötalo) in Helsinki. The unit in Viikki Environment House has the nominal power output of 90 kW and the total energy capacity of 45 kWh. The automatic control of the SieStorage in Viikki has successfully carried out the regulation tests. This means that the SieStorage system itself is able to take part in the reserve markets. (Ojanen 2016)

Ojanen (2016) has covered in his thesis widely and in detail the qualities and capabilities of the SieStorage. The focus of his thesis is mostly on the reserve response aspects. Therefore in this thesis only the reserve response aspects of the battery are taken into account as a part of the microgrid since that technology has already be proved to function properly. Load shifting dimension of the electricity storage is therefore left out of the scope of this thesis. Naturally, in the case Sello this functionality can be used in reality.

In this project the SieStorage won't be used only as a battery storage taking part in the reserve market. It will also be a vital part of the microgrid. As calculated later in the chapter 6, the reserve operations create the main income gained with the battery, but it has many other functionalities too:

- Storing the excess solar power for later use
- Storing the electricity bought during cheap hours for more expensive ones
- Cutting the maximum power need from the grid

The electrical output power of the solar power plant that will be installed is smaller than the normal daytime power need of the shopping center. The missing power will be then provided from the grid or from the battery. Still, sometimes the case may be also that the solar power production is higher than the power need. Such situation may appear for example on a sunny Sunday morning, when the shopping center hasn't been opened yet, but the solar power production is almost on full power.

Since the solar power production basically never matches exactly with the power demand, the battery is a key element of the microgrid. Bruch and Müller (2014) have estimated that that the combination of solar power and electric batteries is going to be an interesting option as an energy supply. Still at the time of the study, the return of investment of both solar power and batteries was less than half of the return of investment of solar power alone. (Bruch and Müller 2014)

On the contrary to the study by Bruch and Müller (2014), in the project of shopping center Sello, the battery is not only used for storing the excess of the generated solar power. The electricity storage can be used as a power reserve as presented earlier. It also makes it possible to buy cheap electricity for example during the night-time, store it in the battery and use later during the day when the price is high. Naturally, all of these actions can be operated within different combinations.

3.3. Solar Power Plant

The project will include the installation of at least one solar power plant on the roofs with peak power output of 500 kWp approximately. Second solar power plant is an optional extension for the project or a separate project to be built in the future. For the second solar power plant car sheds would be built on top of the roof top parking spaces and the solar panels would be installed on those. The total peak power capacity of the second solar power plant is estimated to be around 1 MWp. But since the 1 MWp solar power plant is an optional extension of the project and propably won't be built during the first phase, only the 500 kWp power plant is taken into consideration in this thesis.

In an interview with the reserve experts of Fingrid it was made quite clear that the solar power, along with wind power, isn't very suitable for reserve operations in small scale when applying the current rules (Jäppinen and Kuivaniemi 2017). This is due to the fact that the weather can change rapidly. For example, on a clear, sunny day when the solar power plant is producing electricity with the full power for Sello, the production could go down maximally 500 kW, if needed. But what if it becomes cloudy during the lowered production? The production flexibility would disappear as the clouds cover the Sun and it's not anymore possible to raise the production back to the same level as it was before the lowering.

These kind of situations create a dilemma, that the experts of Fingrid didn't want to speak out directly, whether the solar power can be used for reserve operations or not. Nevertheless, they still showed interest to examine the possibilities of the reserves created from weather-dependent production and the solar power plant of Sello could serve as a pilot project in the future. (Jäppinen and Kuivaniemi 2017)

For the reserve operations of the weather-dependent production the geographical distribution is one of the most important key elements and another one is the combined production capacity that should be big enough. The geographical distribution lessens the sudden affects of the local weather changes as the clouds for example don't hide the Sun the same time in all locations. The production capacity great enough in its turn can provide the required flexibility in all situations.

In the future, this kind of weather-dependent power plants with reserve operations ability could become more and more common in Finland, when the solar and wind power plants are built around the country. Those all could be connected to a central control center, where they are aggregated to be offered to Fingrid as one reserve provider. At the moment the slowing factor for this kind of projects are among others the high investment costs, long payback periods and the challenges of the geographical distribution. Also the challenges and questions of the new technology shouldn't be ignored, when thinking about the private investor's willingness to invest in something that is completely new and never done before.

As presented in the chapter 1, the prices of the solar panels have been coming down for the previous years and the trend is expected to continue in the near future, so the investment costs shouldn't be anymore that big obstacle. At the same time the payback periods get shorter as the investment prices sink, and the efficiency of the panels improves. The challenges of geographical locations and new technology won't disappear.

The IT-connections and the remote access to the distributed power plants can reduce the need for the on-site maintenance, but some on-site maintenance will still be required. Also, the challenges of the new technology remain until some pioneer-spirited company actually executes the first large scale project. Further studies and detailed analysis should be executed to minimize the presented risks.

In the project for shopping center Sello, the solar power production won't take part in the reserve markets. This is mainly because of the lack of the geographical distribution of the solar power plant of the project, but also because of the missing experience and rules of the reserve operations of the weather-dependent production in Finland.

3.4. Lighting

Most of the lighting in the public areas of the shopping center Sello will be changed to more energy efficient options in the project. At the same time most of the new lights will be connected with DALI (Digital Addressable Lighting Interface) connection to the building automation system so that they can be controlled remotely.

In the project, the DALI connection makes it possible to regulate the lighting according to the frequency changes in the grid. This way the lighting will become a part of the power reserves in Sello. The lighting can be controlled in many ways: it is possible to turn off for example every third lamp everywhere or every second lamp in certain areas, tune all the lights down by 20...30 % or make them shine brighter for a moment. The command will depend on the frequency of the electricity grid and the predetermined conditions of the area where the lighting is located.

Luoma (2015) has shown that 30 % power drop from the normal situation will hardly be even noticed. His study was conducted in a classroom environment and the results were gained with a short questionnaire, in which most of the answerers said that they didn't see any changes in the lighting during the test. The same principle applies to the increase of the lighting intensity as well. (Luoma 2015)

Obviously, there are also areas, where it isn't possible to use all options. For example in the parking hall, there isn't basically any natural light at all, so it's never possible to turn off all the lights, since it could cause hazardous risks and situations. Still e.g. 10 % adjustment could be possible. Therefore, safety issues always have to be considered when creating such lighting systems and take them into account as limiting factors already in the designing phase.

There are basically two different ways of controlling the lighting. As the first option, if it's possible to adjust the brightness of individual lamps continuously, all the lamps can be dimmed or brightened for example by 10 percentage points, when the starting level is 90 % of the maximum brightness. As the second option, it's possible to have every tenth lamp off in the beginning and the same amount of lamps available to be turned off, if needed, in order to achieve the same reserve capacity. Naturally these two sets of lamps must be controlled separately. The easiest way is to have three separate electric circuits with on/off switch: two for the regulating lights and one for the rest. Both of these options give the power flexibility range of 80…100 % of the maximum capacity.

The chosen option depends strongly on the wanted qualities and profitability. Lamps that can be dimmed are generally more expensive than the ones that only turn on and off. Also the connection for controlling of all lights with DALI is a more massive installation than connecting lamps only with a normal electric circuit. But the bigger investment also brings along far more flexibility.

Instead of just having the 10 % regulating capacity, the first option allows adjusting in the range of 0…100 % of the maximum power and the regulation can be done by e.g. every 1 or 0.5 percentage points. On the contrary, the second option has regulation capacity points only at 0 %, 80 %, 90 % and 100 % of the maximum power. Also it is not be desired to have spots without any lights or with only poor lighting inside the building in public areas, unless enough natural light can be provided.

The first option enables for example controlling the lights based on the presence. Besides this, the first option allows also to adjust the lighting level according to the natural light in order to save energy by making sure the overall lighting level stays constant in the area when the intensity of the sunlight changes over time. Both ways of controlling the lighting have already been used for years and are well approved technology.

As a conclusion, both of the options are possible to be used as reserve capacity, but they both have their pros and cons. The first option is much more flexible but the investment is greater. It is a better solution for public spaces, where the comfort is the number one priority.

The second one is cheaper as an investment, but it suffers from the lack of flexibility. This solution could be a possible option for spaces that aren't used that frequently and there isn't a need for full lighting always. One example are corridors and storages that have many lights, are used only by the staff and have the lights on throughout the day, but they are not used all the time.

All in all, the lighting can be used as a reserve, but dropping or increasing the power of the lighting cannot be done too fast. Otherwise, it would be noticed by too many people. Since Sello is mostly a public place, where the comfort of the people is on a high priority, majority of the indoor lighting will be controlled in the way explained in the first option.

Most likely field tests are needed before the system can be taken into active demand response use in the shopping center. Careful planning is also always needed, so that it's perfectly clear, that in what kind of situations the power regulation of lighting can be used and in what kind of situations not.

3.5. Outdoor Ground Heating

The Sello shopping center is located in a very central place next to a one of the busiest train stations of Espoo and next to a large bus station. This means that there are a lot of people walking by the shopping center every day of the year in all times of the day even when the shopping center itself is closed. The premises of Sello should therefore always be kept in a great condition so that the passenger traffic wouldn't suffer from external obstacles.

In the summertime there are usually no hindrances except for the ones caused by construction and maintenance works. But during the Finnish winter, it's a completely different story. The cold weather, snow and the darkness will create dangerous environment, if nothing is done to prevent these conditions. The darkness can be solved with sufficient lighting but still the snowfalls and coldness cannot be prevented in the outdoors.

The fallen snow can first be ploughed away from the streets and yards with e.g. tractor. Then it should still be driven away from the premises with trucks. Also gravel or salt has to be spread out on grounds after ploughing in order to avoid slippery conditions. The problem with this is that the snow ploughing of the large areas has to be done with heavy machines moving among the people.

First, this can cause obviously safety issues when people are walking in the narrow and slippery passages around the moving machines. Secondly, the ploughing and the transportation of the snow to somewhere else cost a lot of money, not only because of the work but also because the operating staff has to be available 24/7 throughout the winter.

When the fallen snow would be removed, the cold weather could still cause problems since the moisture in the air could condensate and freeze on the cold surfaces. Also spilled drinks and other liquids would freeze on the ground. All these events would cause the grounds to be slippery, either everywhere evenly or locally. Even if gravel or salt would be spread out on the ground, they can't reach all surfaces evenly. All the same, the slipperiness has the potential to cause serious injuries for the people walking outside.

Ploughing the snow clearly isn't the optimal overall solution, but what could be then? In Sello this has been solved by heating up the outdoor grounds. The heating units are assembled inside the ground. The ground is heated up either with district heating water or with electric heating cables. This thesis focuses only on the electricity reserves, but the district heating water must still be circulated through the pipes. This is done with pumps, which can be used as a reserve too. The electric heating units and the circulation pumps are listed in the appendix D.

Currently the outdoor ground heating is optimized based on the weather data and forecasts, so that the heating would be energetically optimal on all times. The microgrid solution and the reserve operations may change the current optimizations slightly, but still it shouldn't have a significantly huge impact in the long term.

In practice, this means that in the wintertime the ground heating can be turned off if there is a shortage of power. On the other hand, in the summertime if there is too much power and all the useful capacities in Sello are on full power, the ground heating can be turned on. Even though this sounds like a waste of energy, and actually that's exactly what it is, it may be a necessary action in order to maintain the power balance in the grid.

Obviously, turning on the outdoor heating units in the summertime should be the last option in the tool box, since it's much more beneficial to for example to cool down the shopping center little bit more for a while or charge up the battery storage for later use. But if all of these far more reasonable options have already been used or some equipment are for some reason out of order, the ground heating units can be considered as a "reserve of the reserves" to fulfil the offered capacity.

The outdoor ground heating units are taken into consideration in the calculations as a part of the microgrid all year round. That means they could be part of the reserves even in the summertime, when they are not normally operated. Naturally, they aren't necessarily used as a reserve, but the option is left available. The choice is also made in order to simplify the calculations.

Fingrid rules for FCR markets don’t allow the aggregation from separate energy balances at the moment and in the conducted aggregation pilots the aggregated units must have had symmetrical frequency control ability (Fingrid 2017s).

In the microgrid solution, the aggregated units are inside only one premises and one energy balance, so the symmetry requirement doesn’t concern the individual units, but rather the whole microgrid. This makes it possible to use the individual, asymmetrical units together as a single reserve. Of course, the unit can adjust symmetrically, but that is not required by Fingrid. Instead, one unit can compensate the other units for achieving the best result.

4. Operating the Microgrid as a Reserve

As presented in the chapter 3 and appendix 3, the microgrid consists of many separate units and equipment that are arranged into one centrally controlled system. Some of the units are able to operate as reserves, some have limitations and some cannot at all, at least under the current rules. The ones that can participate the reserve markets all times are the ventilation, the lighting and the battery storage.

The outdoor ground heating units and the solar power plant have some limitations for participating the reserve markets. The outdoor ground heating can be used mostly only outside the summertime. In the simulations the restrictions of outdoor ground heating units are left out of the consideration, but in reality these have to be considered very carefully.

The solar power plant cannot participate the reserve markets for the reasons presented in the chapter 3.3. Possibly, solar power plants will be able to take part in the reserve markets, if the market rules allow it in the future. This may require special exceptions just for the renewable, weather-dependent energy sources. That is why the solar power isn't taken into account in any way when the simulating the possible income from the reserve markets.

Ojanen (2016) has described the operation of the battery storage as a reserve widely in his thesis. Therefore in this thesis it's focused mostly on the other parts of the microgrid such as ventilation and lighting, whereas the battery storage is only considered as a supporting system. For example, it can compensate sudden reserve responses taking place in the microgrid because of a sudden change in the frequency of the national grid. This allows e.g. the lighting level to change slowly so that no one really notices the change instead of suddenly dimming or brightening the lights.

The daily operations are executed by the Microgrid Energy Management System (MEMS) and the energy specialists of Siemens. The MEMS platform takes into account e.g. the weather forecasts and electricity spot prices. It takes also care of the communications and the data transfers with Fingrid. The data transfer includes e.g. the real-time and historical data. The data transfer between Fingrid and MEMS has been illustrated in the figure 4.1 as well as the necessary data produced by a weather data provider and Nord Pool.

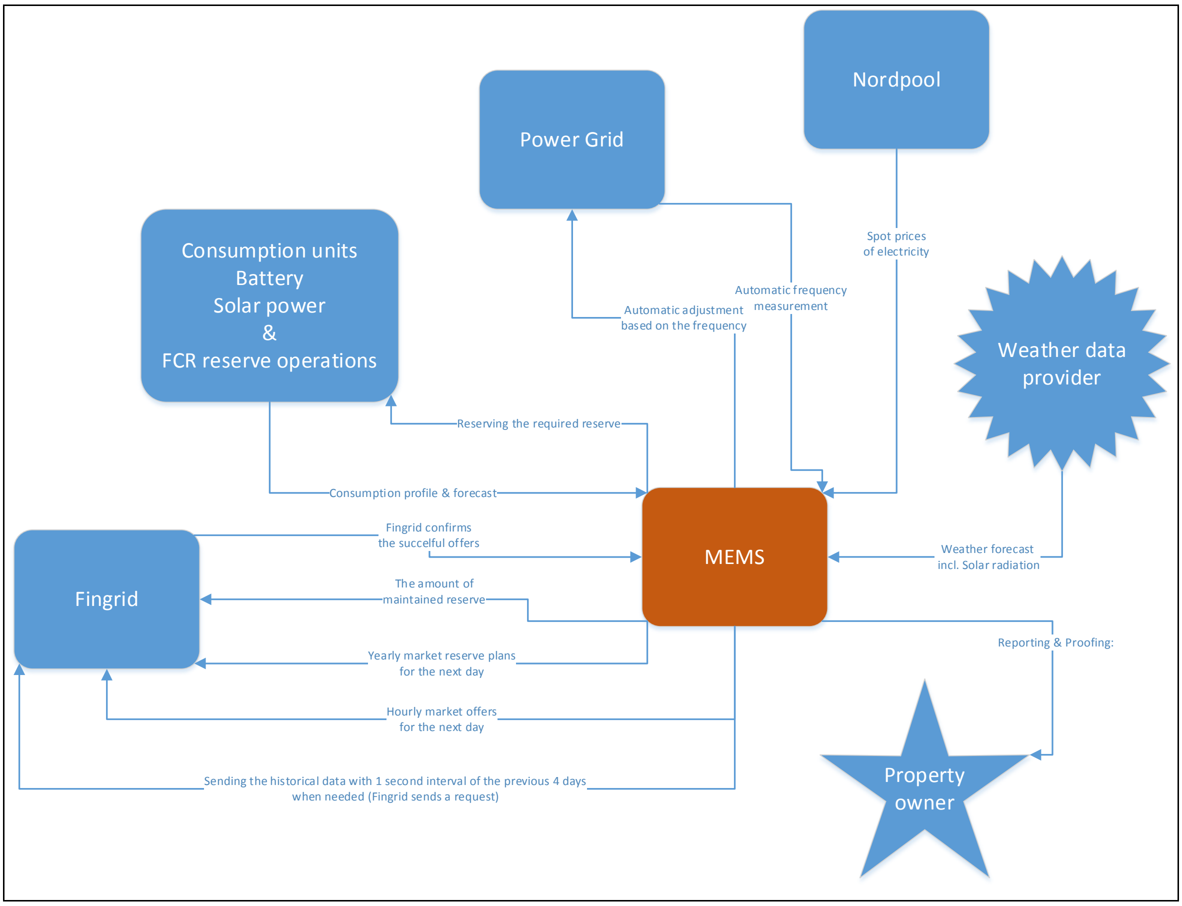


Figure 4.1. A simplified illustration of the data transfer needed for operating the microgrid.

As the figure 4.1 presents, the amount of information is tremendous and different kind of data are coming from many different sources. It's impossible to handle all data manually. Therefore the MEMS is needed to do all the actions automatically. In the context of the microgrid solution, the input power of the reserve responding units will be changed automatically by the MEMS.

The MEMS will do the FCR regulations for the microgrid units based on the frequency in the grid. It will additionally take into account the Nord Pool spot prices, the electricity production from the solar power plant and back-up generators and weather forecasts. It also provides the data that is used for reporting the wanted and needed information, such as gained income and indoor conditions, to the shopping center Sello.

4.1. Connection to Fingrid

When a power resource is planned to be offered as a reserve to Fingrid, firstly it has to pass the regulation tests. Secondly, it has to have the required communications with Fingrid. In this thesis it's focused only on the communications needed for the FCR markets, as the FCR-N and FCR-D markets are the main reserve markets that the shopping center Sello will participate. The FCR-N and FCR-D markets have mostly the same rules for the communications. Therefore they will be referred as FCR markets in this chapter, when the rules are the same. The FCR-N and FCR-D are separated when they have different rules. The same is done with the yearly and hourly markets too.

On the yearly markets, the reserve provider has to send the reserve plans with the maintained power capacity for each hour of the next day by 6.00 pm CET. CET time zone is used to avoid mistakes, because the Nord Pool operated with the CET times too. The reserve plans are sent with the accuracy of 0.1 MW. (Fingrid 2017a) Based on the yearly markets contract, all the provided capacity will be bought (Fingrid 2017w). Fingrid doesn't send back a confirmation message of the received plans.

In the hourly markets, the offers for the hours of the next day must be submitted electronically by 6.30 pm CET. The offers must contain e.g. the offered hour, the size of the offer for that hour in MW with the accuracy of 0.1 MW and the price in €/MW,h with the accuracy of 0.01 €/MW,h. The given offers are then arranged in price order from the lowest to the highest. All the reserve providers get the price of the highest accepted bid. Fingrid confirms the successful offers by 10.00 pm CET. (Fingrid 2017b)

During the hours, when the reserve is operating, the reserve provider has to share the information of the maintained reserve at least every three minutes to Fingrid. This information is called as real-time data. Additionally, on request made by Fingrid, the reserve provider has to sent the unit-specific historical data of the active power of the units contributing to the regulation with the time interval of one second. The historical data must be stored at least for four days. This information is used to verify the provided reserve capacity e.g. in the case of disturbances. (Fingrid 2017a)

The simplified information exchange between Fingrid and the MEMS has been represented in the previous chapter in the figure 4.1. In the same figure, other important information sources have also been represented. Such information sources are spot prices of electricity and weather forecasts, which have to be taken into account too in the daily microgrid operations.

According to the interview made with Jäppinen and Kuivaniemi (2017), when considering the shopping center Sello, it's not necessary to send the information of each ventilation machine, ground heating unit etc. separately as the work needed to analyze the data would be tremendous. Instead, the information should be gathered together in a form, that can provide the needed information without the need that Fingrid has to observe every small unit separately. (Jäppinen and Kuivaniemi 2017) The simplest way to do this is to provide the data of the main meter.

In the context of a shopping center, where the electricity consumption is nowhere close to constant during one hour, the verifying of the reserve responses with the main metering sets challenges. In the figure 4.2 is presented an example of the behaviour of a consumption-based reserve during one hour between 10.00 to 11.00 am. The light blue box represents the change of behaviour that can certainly be said that it is due to reserve response. The light orange box represents the change of behaviour that can be said to due to the reserve response, but there may be some concern if the reserve response has been fulfilled. The green box indicates the change of behaviour that with the most certainty wouldn't be accepted as reserve response even if the corresponding capacity would have been provided.

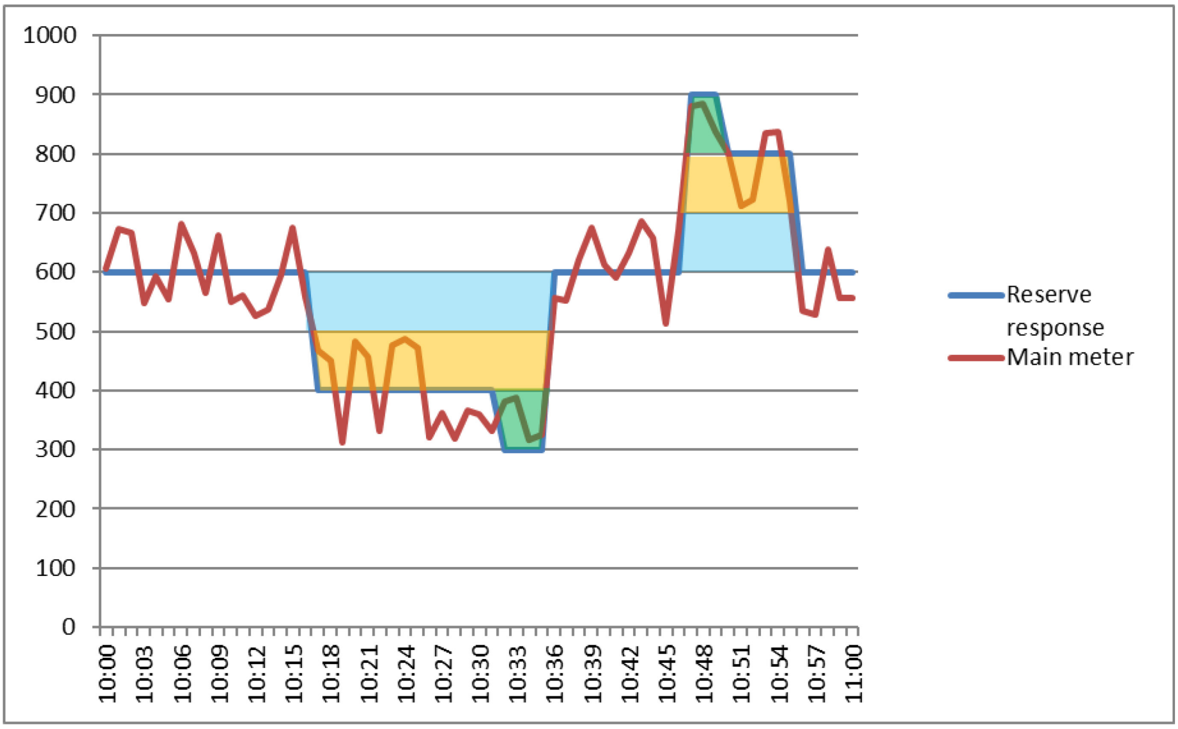


Figure 4.2. An example of power metering of main meter and the actual reserve response of a reserve provider during one hour. Light blue areas represent the reserve responses approved without a doubt, light orange areas may raise some concerns and the green area wouldn't be approved without strong additional proofs.

According to the figure, the main meter cannot separate the reserve responses accurately from the other consumption. This causes the proofing of the executed reserve responses to be challenging. The light blue areas would be easily proven with the main meter. To achieve the offered capacity, some additional capacity should be activated which means all available capacity can't be offered to Fingrid. That means that the income from this model would be significantly lower compared to the others.

The light orange areas could be accepted as the fulfilled reserve response but some questions may arise from Fingrid's side. Proofing this would require additional data to prove that the actions have been executed and it wouldn't differ from metering all the units and providing this data to Fingrid in the first place.

The green area wouldn't be accepted in any case without strong additional data, as it cannot be shown that the actions have been executed fully since the overall consumption hasn't changed as much as the reserve response should have been. Also in this case metering all the units would be needed and it wouldn't differ from providing that data to Fingrid in the first place.

Providing all the data to Fingrid isn't really an option except for special cases, since they don't want the data of many small units (Jäppinen and Kuivaniemi 2017). Providing the light red area of the main meter as the fulfilled reserve response can be a good solution, if the data of all of the units can't be provided for some reason. Also, if e.g. a factory has only few processes that are dominating the power need, the main metering can be satisfactory.

Otherwise one possible solution is to aggregate all the units as one and provide this data to Fingrid. This requires additional work on the reserve provider's behalf, but it makes it possible to capitalize the maintained reserves fully. Most likely new meters would be needed for proofing the reserve responses.

It should be noted though, that the units that are not taking part in the reserve response shouldn't start compensating the actions made by the units that are participating the reserve response. An example of the compensation effect of ventilation has been described in the chapter 4.2.1, but it doesn't mean, that the compensation effect couldn't happen with other kind of resource as well.

4.2. Microgrid Modes

A shopping center can be described as a living organism: it never stays still and rests, rather it keeps evolving, changing and reacting to the events of the outside world all the time. The consecutive weeks, days and hours are not similar. One day or one hour the shopping center has only a few visitors, the next one it's practically impossible to walk the aisle from one end to another without bumping into others. For example, mornings are significantly different from afternoons, when people have more free time than in the mornings. The same applies to the working days compared to the weekends as well as to the holiday seasons compared to the working weeks.

This is why there is a must to have different ways, or modes, to control the demand response actions, so that there are always suitable settings corresponding to the situation. After all, demand response is only an additional benefit for the shopping center; the customers are always the main target of the business. The demand response shouldn't in any case cause discomfort for the customer or neither for the labour force in the shopping center.

In the following chapters different kind of modes are introduced. It's also explained how these modes are operated and for what kind of situations they are suitable for. In many cases, the modes don't appear individually; rather in the normal situation combinations of different modes take place. In order to simplify the examples, here the modes are represented only one by one.

4.2.1. Individual and Areal Demand Response

The simplest DR action is to control individual unit or units that affect only one restricted area. In a shopping center this kind of case could be for example a single air handling unit or the lighting of one floor. This kind of regulation is easy to handle and the conducted actions are easy to prove when needed. Depending on the qualities and the quantity of the units, they can be operated by turning them on or off, changing the power need in steps or gradually. The FCR-N rules require almost linear adjustment, where as the FCR-D rules have the chance to choose between almost linear adjustment and on/off switching if suitable.

Usually one space is controlled by one air handling unit. Two or more air handling units are used when the space is too big for one unit to handle and in this case the space is separated into corresponding number of zones. If it's considered a single air handling unit with a frequency changer, the changing of the input power can be almost continuous with very small steps. Therefore, the frequency changer allows quite exact power controlling of the unit. The same principle applies, if there should be more than one unit per space.

When there are more than one unit in one space, it should be noted that the balance between the individual units must be maintained. Otherwise there could be events taking place, when one unit starts to compensate the parameter changes caused by the other unit. Such events can be for example changes in the CO_2 concentration in the exhaust air and in the indoor temperature.

As an example, let's say that there are two similar units controlling the climate of one store in a shopping center and first one of them decreases the air volume brought to the store because the grid frequency lowers. This causes the CO_2 concentration to start rising and especially in the summer the room temperature would start rising too, as less cool air is brought to the space, but the heating power of the customers, lamps and other electronics stays the same. As the power of the first unit has already been forced down and is still forced to stay on the lower level, it cannot start adjusting the conditions back to normal. Instead, the second unit would start compensating the lack of capacity of the first unit.

This means that the second unit needs more power and the reserve response made by the first unit isn't complete. As an example, in the figure 4.3 is a graph of the power input of two similar air handling units as a function of the percentage of the dimensioning pressure. Initially the both air handling units are operating at the same power. The first unit starts the DR but the second one doesn't participate to this. This results to the situation that the second unit starts to compensate the first one after awhile. In the graph, the blue arrow represents the adjustment made by the first unit as a reserve response and the red arrow represents the compensation made by the second unit.

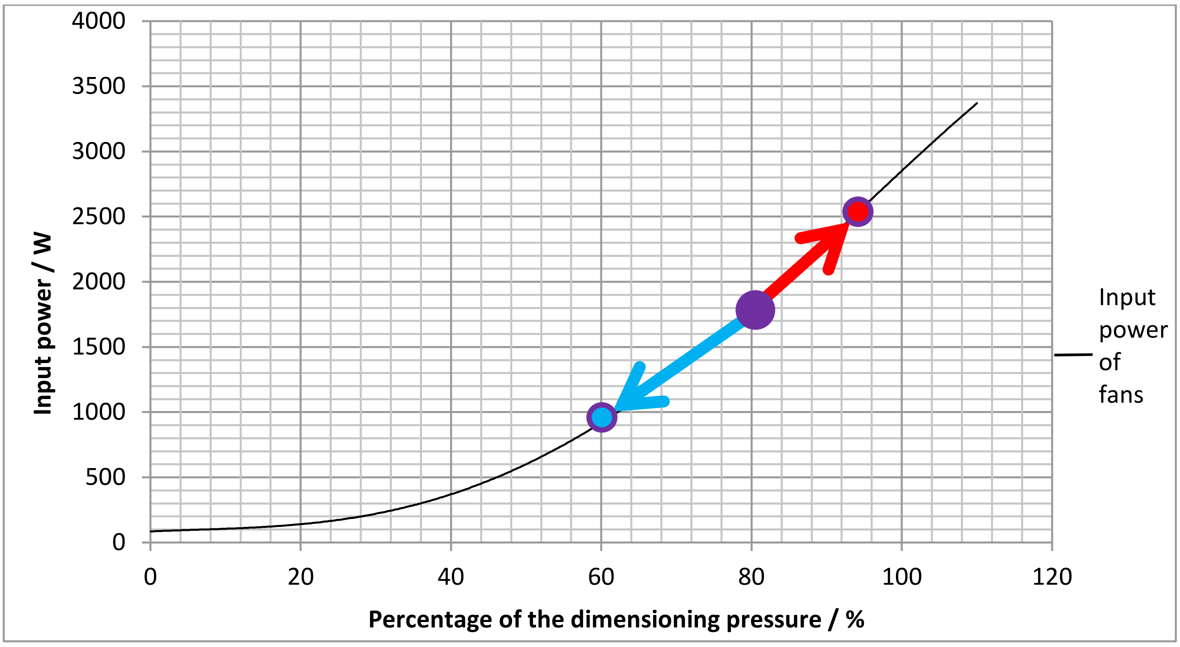


Figure 4.3. An example of the input power of two similar air handling units as a function of the percentage of the dimensioning pressure. The blue arrow represents the demand response made by the first air handling unit and the red arrow the compensation made by the second unit.

In the graph the compensation is smaller than the actual demand response. This is the case when the demand response doesn't last for long. As the measuring parameters, like the CO_2 concentration and the temperature, change over time, the short demand responses should rarely cause significant compensation reactions, but longer ones can even increase the total power need instead of lowering it. Therefore, all the units affecting the same area should always participate the DR simultaneously.

The lighting of one area has more options since there are much more units in a single area than air handling units, but at the same time it's easier to handle since the compensation effect doesn't occur. The power regulation capacity of the lighting is although usually lower than the regulating capacity of air handling, since the lighting cannot be as easily adjusted as the ventilation without disturbances.

The individual demand response is already used in the industry, where a single process can be operated differently than normally based on the grid situation. For example, a powerful pump can fill up a reservoir with water, when the power production is higher than the consumption. In other words, when the frequency is over 50.00 Hz. The pump can then be turned off or slowed down when there's lack of power, but the production that needs water isn't interrupted, as the filled reservoir can be used in the following process phases. In this example the pump is the individual power reserve and it's comparable for example with the ventilation units in the shopping center.

4.2.2. Circulating Demand Response

The circulating demand response is a variation of the individual and areal demand response. In the circulation mode separate individual units or areas executes reserve response actions on their turn, so that there is always the same amount of reserve capacity available on all times. In the table 4.1 it is presented a simple example with four different factories with different amounts of flexible capacity and how long the reserve response tops can last. It is assumed that the capacities fulfil the requirements for the FCR-N markets.

Table 4.1. An example of the qualities of the units to be utilized in the circulation mode

	Maximum flexible capacity (kW)	**Maximum duration (min)**
Factory 1	300	30
Factory 2	100	10
Factory 3	200	30
Factory 4	100	20

Even though all the four factories have enough capacity to enter the FCR-N markets alone, they couldn't participate the reserve markets since none of them alone could provide reserve response for the full hour. But instead, the four factories could be seen as a pool, from which it's possible to choose the right reserve providers for the right moment. This is called aggregation.

By aggregating the loads of the factories, they are able to participate the markets together. For example, if the Factory 1 collaborates with the factories 2 and 4, they can offer 100 kW of reserve capacity since the factories 2 and 4 cannot deliver more capacity. This is not the only option, though. The Factories 1 and 3 can together offer 200 kW of reserve capacity for the full hour, when one follows the other in reserve operations.

If all of the factories collaborate, they can offer 300 kW of capacity to the markets for one full hour. In this case the Factory 1 could operate first alone for 30 minutes, then the Factory 3 would operate together with the Factory 4 for 20 minutes, after which the Factory 3 would continue with the Factory 2 for the last 10 minutes to fulfil the 60 minutes.

The aggregated units could also be individual small capacities such as electric heating units of households. It's likely, that all of them couldn't be operated as a reserve for the full hour. Therefore much more coordination would be required for efficient reserve utilization. Surely a maverick aggregator would be needed for the coordination and daily operations of the aggregated assets as the individual reserve providers probably wouldn't be interested in or even be capable of doing this.

The aggregation option creates a new dimension for the daily operations and a source of income for all of the reserve providers. They couldn't achieve this by themselves. At the moment, the market rules of Fingrid allow the aggregation only on some markets. It is expected that the aggregation will become a normal option for the reserve providers on all markets during the next few years (Fingrid 2017s).

From the perspective of Fingrid, it's a more desired situation, if all the actors offer as much capacity as possible. The need for flexible consumption is increasing constantly, as argued in the chapter 1. The higher supply should decrease the reserve prices as well, based on the principles of the supply and demand. The profitability of aggregated assets for the reserve providers depends on the way the profits are shared. Fingrid has piloted one model for FCR-N markets, but the model most likely won't be the same one which will be used in the future (Fingrid 2017s). Therefore, any possible profit share models are not introduced here.

In the microgrid perspective, the same kind of circulation model can be used for the individual units such as ventilation machines, battery storage, outdoor ground heating and lighting. Since there are plenty more individual units in the shopping center than only the four factories in the given example, the controlling of all the units is consequently much more complex and there are even more combinations to control them together. Therefore it isn't possible to control them manually in any way. Controlling the units is one of the most crucial parts that the MEMS has to do.

In the microgrid the circulation will mainly be used for the ventilation and possibly for the outdoor ground heating units. This allows to maintain for example good air quality in the individual areas even during the reserve response. Suitable time for the reserve response in one area could be e.g. 10...15 minutes.

The minimum number of participants for the circulation is two, naturally, but in the case of ventilation more realistic number could be 3...6. This would allow one participant to take part to the demand response only once or twice per hour. That way the air quality in one area wouldn't suffer too much during the operating hour.

The outdoor ground heating units can be operated with the circulation as well. In this case the units are turned on and off one after the other, or the input power of individual units is changed linearly, when it's possible. As the ground temperature doesn't change immediately, turning the units off for a short time shouldn't have a significant effect on the energy consumption of the units.

4.2.3. Total Demand Response

The third reserve response mode is the total demand response (TDR). In the TDR all the reserve units in the whole premises are active and ready to react to the reserve commands at the same time. This means that there isn’t any excess capacity or its amount is very limited to be used for e.g. circulation purposes.

Subsequently, the TDR requires extremely careful and detailed planning beforehand, since the offered capacity has to be provided, even if e.g. indoor climate conditions would get really bad during the reserve response. Otherwise the reserve provider has to pay a penalty fee predetermined in detail in the contracts between Fingrid and the reserve provider (Fingrid 2017k) (Fingrid 2017w).

Therefore the TDR shouldn’t be performed unless, it can be made sure that it doesn’t cause any significant harm inside or outside the premises. For example a Friday afternoon, when the shopping center is full of people shopping, dining and doing groceries for the weekend, isn’t obviously the most desirable time to turn off the ventilation units. Also dimming the outdoor lights too much in the middle of the night may not be the safest option.

It should be mentioned, that the TDR doesn’t take place only, when the overall maximum capacity is at its limits. It can also take place, when the offered capacity is well below the overall maximum, but there isn’t really any excess capacity to be used as a replacement. That is why the TDR might actually be a more common situation in reality, than it first sounds like. The TDR can be almost a daily situation, but this cannot be known until the microgrid has already been operating for some time.

After all, the careful planning is the key to the success when regarding the TDR. It is naturally the best option to have some excess capacity in order to fulfill the requirements even in a case of some units might fail to operate. Of course it is also always possible to offer for example 100…200 kW smaller capacity to Fingrid, than actually would be available.

Economically it wouldn’t be the optimal solution, but for example during the first months in operation, it may be the most reasonable option until enough experience has been gained. After this, it is possible to estimate better which units can be used in the TDR and which cannot.

Based on the practical experiences, the microgrid operations become more optimal day by day. Not only will the TDR be optimized, but also the areal and circulation modes become more efficient. The energy usage will ultimately be improved so that the most beneficial parts of the microgrid in each situation are primarily utilized.

But as being said, operating a microgrid optimally is an issue, in which the practical experience matters a lot and it can’t be described more until the system has been running for some time already. Therefore the best practices can’t be described yet in this thesis and further studies are needed in order to find those.

5. Calculations

In this chapter, it will be calculated how great the yearly benefits can be generated for the shopping center Sello with the microgrid solution. Only the reserve response functionality will be calculated in this thesis.

Sello could take part to the yearly and hourly markets of the FCR-N and FRR-D reserves, but in the calculations only the FCR-N participation is taken into consideration as it has much higher value per capacity unit. Also all units of the microgrid, that are used in the calculations, fulfil the requirements defined in the FCR-N market rules.

The solar power plant cannot participate the reserve markets for the reasons presented in the chapter 3.3. Possibly, solar power plant will be able to take part in the reserve markets, if the market rules allow it in the future. This may require special exceptions just for the renewable, weather-dependent energy sources. That is why the solar power isn't taken into account in any way, when simulating the possible income from the reserve markets.

The units, that are participating to the FCR-N markets in the calculations, are the ventilation units, the outdoor ground heating units and pumps and the battery. Their combined reserve power is slightly over 2200 kW. 2200 kW is used as the maximum reserve power in the calculations, since naturally more than what is available, cannot be offered. Also it is a good solution to have some safety margins because of the reasons explained more detailed in the chapter 4.2.3.

The prices on the FCR-N yearly and hourly markets are based on the market prices of the years 2013-2016. The FCR-N hourly and yearly market prices, that have been used in the calculations, are available on the web pages of Fingrid (Fingrid 2017i) (Fingrid 2017v).

If some units wouldn't pass the requirements for FCR-N markets, they could possibly participate the FCR-D markets. The income from the FCR-D markets could be calculated the same way as the income from the FCR-N markets. Like the FCR-N market prices, also the yearly and hourly market prices of FCR-D are available on the web pages of Fingrid (Fingrid 2017h) (Fingrid 2017v).

There are some very important shopping periods for Sello during the year, such as the Christmas time, the sales after that and sales week "Sembalot" that occurs both in the spring and in the autumn. Financially these periods are so significant for Sello, that the demand respond cannot be utilized fully all the times. Therefore, in these calculations the possible income during the daytime of those periods will be left out of the analysis.

The important sales periods, when the reserve response of the ventilation and lighting are not available, are:

- Winter sales period: From Christmas day to epiphany
- Sembalot spring: Mid-March

- Sembalot autumn: Mid-September
- Christmastime: from beginning of December to Christmas eve

In the calculations the winter sales period is expected to last from 25th of December until 8th of January every year. The spring Sembalot is assumed be on the week number 11 and the autumn Sembalot on the week number 38 as they were in 2016. The Christmas time is assumed to start on the 8th of December and last till the Christmas eve. The important sales periods make up altogether around one and half months each year.

Altogether three different scenarios will be calculated simultaneously and there will be altogether ten simulation rounds for each year to avoid singular misleading results. The participation to the FCR-N market changes based on the settings of the scenario.

The first scenario is based on the assumption that the FCR-N participation is only to the yearly markets. It can be said that the risk on the yearly markets is smaller than on the hourly markets, since the price for the reserves operations is constant all year round and Fingrid buys all the offered reserves to the extent of the contract for the yearly markets, even if there wouldn't be any need for reserve operations. Also the yearly market participants are announced in the end of a year, so even if there should be a situation that the reserve offer doesn't qualify to the yearly markets, it's still possible to participate to the hourly markets.

In the second scenario, the reserve is offered only to the hourly markets of the FCR-N. This market is slightly riskier than the yearly markets, since the fluctuation of the prices is great. At the lowest the price is 0.00 €/MW,h or close to that, but the high peaks can often reach even beyond 100 €/MW,h. Therefore, the timing can be crucial for profitability. The reserve capacity should always be available when the peak hours occur to maximize the income. The low-price hours in the reserve market instead make it possible to capitalize the spot price differences between the consecutive hours. For example, the battery can be charged full with excess solar power and cheap electricity, which can be used later when the electricity is more expensive.

The third scenario starts with the assumption that 1000 kW of the reserve capacity has been offered successfully to the yearly markets, and when available, the excess capacity can be offered to the hourly markets. In a way, this scenario has the biggest risk, since the FCR rules require that the yearly market volume must be fulfilled first. When the yearly market volume has been fulfilled completely, the reserve provider can participate to the hourly markets. This means that the reserve provider won't benefit from the expensive hours, if the yearly market share hasn't been fulfilled.

On the other hand, the share on the yearly markets guarantees always some income even if there wouldn't really be any need for the frequency regulation or the hourly market offer wouldn't be successful. The hourly market offer could fail, because of too high price or any regulation capacity wouldn't be needed at all from the hourly market during the certain hours.

The timing is the main problem with the optimization and risk control with the reserve markets and utilizing the spot price differences. For example, what is the best option, if the price of the electricity is first low and the reserve operations empty the battery during that time. Then the price of electricity rises significantly. Would it have been actually better to just charge the battery full and then discharge instead of using it as a reserve?

On the other hand, the battery could have been charged full during the hour with reserve operations too. The same applies to the ventilation and outdoor ground heating, as the excess and deficit of the “heat and oxygen storages” can be balanced relatively soon after the conducted power control actions. Obviously, for lighting, this isn’t applicable, as the light cannot be stored.

The presented optimization is certainly really difficult to model properly and it is therefore left out of this thesis. Instead it will only be calculated, how great the income from the FCR-N markets could be with the microgrid units listed in the appendix D and the SieStorage battery.

The income $P_{x,n}$ from the hourly market of the hour n of the year x is calculated with

$$P_{x,\mathrm{n}} = P_x(n) * C_x(n) \tag{1}$$

where the $C_x(n)$ is the maintained and sold capacity during the hour n of the year x and $P_x(n)$ the hourly market price per regulation capacity unit for the corresponding hour.

For the yearly market the $P_x(n)$ is constant all-year-round so the equation can be simplified to the following expression

$$P_{x,\mathrm{n}} = P_x * C_x(n) \tag{2}$$

where P_x is the yearly market price per regulation capacity unit

The yearly income $P_{x,tot}$ from the reserve markets can be calculated with the equation 1 by summing the income of all the individual hours of the year x. For this purpose, the equation 1 can therefore be transformed into the form

$$P_{x,tot} = \sum_{n=1}^{8760} P_x(n) * C_x(n) \tag{3}$$

For the yearly markets $P_x(n)$ is constant throughout the year so consequently the equation could be simplified to the following expression

$$P_{x,tot} = P_x * \sum_{n=1}^{8760} C_x(n) \tag{4}$$

where P_x is the yearly market price per regulation capacity unit. The equation 4 could be used for calculating all the FCR-N income in the scenario 1 and in the scenario 3 the part that is connected to the yearly markets. In any other case the equation 3 should be used.

The income from the FCR-N markets was calculated with the Microsoft Excel. An example of the formula scripts used in the cells are presented in the appendix A. The market data with prices and traded volumes was collected from the open database of Fingrid. The important sales periods are taken into account by the reserve response capacity being unavailable from 8.00 am to 9.00 pm during those periods, but it is available in the night time.

The source of the capacity at the certain time is neglected in the model, since it is irrelevant. This is because every unit of the provided capacity is anyways able to fulfil the FCR-N requirements themselves too. Therefore, there’s no need to specify the used reserve units more detailed.

The overall capacity of the shopping center Sello is approximated with a random natural number between 0 and 2200 kW. 600 kW of this is assumed to be from the building technology such as ventilation and outdoor ground heating. The rest, 1600 kW, is based on the power capacity of the battery.

The 2200 kW is chosen as the maximum value even though there is actually more capacity that potentially could be provided in the best case scenario. The limitation is done to have some safety margins for the calculations and to avoid the TDR situations.

After randomly choosing the available capacity, the overall capacity is rounded down to the nearest 100 kW. The reason for this is that the accuracy of the offers to Fingrid should be 0.1 MW and naturally more capacity cannot be offered than what is available.

If the volume of FCR-N on the hourly markets has been zero, the submitted offers are rejected automatically. Still it’s likely that all of the offers wouldn’t be successful even if there should be purchases on the hourly markets. This is because the price set for the offered capacity could have been set too high and other reserve provider would have offered the capacity with lower price. The probability of a rejection is approximated to be 5 %. The approximation is done with a random natural number between 0 and 19, where 0 means the rejection. With the other numbers the offer is accepted.

Then the income of each hour is calculated. When the reserve is participating only to the hourly or yearly markets, the income for certain hour can be calculated directly with the equations 1 or 2, respectively.

When the reserve capacity is participating on the both markets, it has to be first taken into consideration, if the yearly market obligation can be fulfilled. If not, the available capacity can participate only on the yearly markets. If the yearly market capacity can be exceeded, the capacity, that is more than the obligation, can be offered to the hourly market. The capacity that is offered to the hourly markets goes through the same process for accepting and rejecting the offer by Fingrid as explained earlier.

The total yearly incomes of hourly and yearly markets are then calculated according to the equation 3. The equation 4 could have been used for yearly markets too, but in order to avoid calculation errors and typos, the equation 3 has been used for this case too. For calculating the yearly income from the both markets, a more complex application of the equation 3 has been used. The used application takes into account the market conditions explained earlier. The Excel formulas for calculating the income of all cases are represented more detailed in the appendix A.

6. Results

The simulation presented in the chapter 5 for calculating the income from the FCR-N hourly market was ran 10 times for each year. The detailed Excel formulas and scripts used in the calculations are represented in the appendix A. The results of the simulation rounds for each year and scenario are represented in the appendix B along with the simulated maximum, minimum and average values of each year.

In the appendix C, the possible hourly incomes of years 2013...2016 within the three different scenarios have been presented. The figures of the appendix C represent only the results of one individual simulation round for each year.

As presented in the figures 6.1 and 6.2, the hourly markets can provide substantially higher income during some hours than the other options, but also the volatility of the possible income is much greater. At the same time, the participation in the yearly market only or both in the yearly and in the hourly markets would generate relatively steady source of income without a fear of unsuccessful offers.

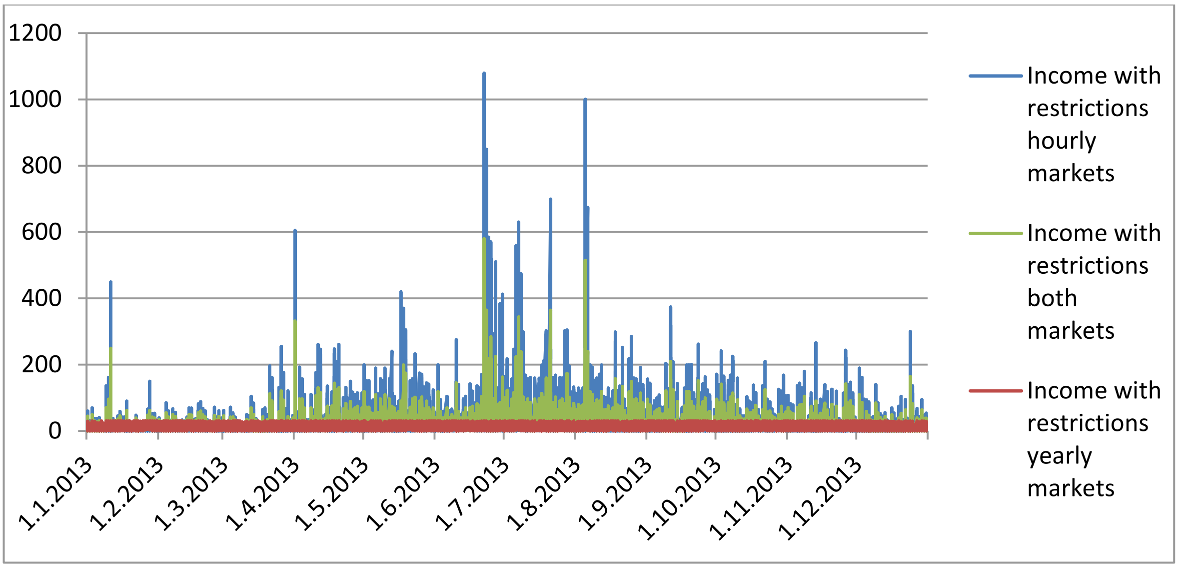


Figure 6.1 The calculated possible hourly income in the three different market participation types in the year 2013.

As the figure 6.1 shows, on the hourly market the possible income during certain hours could have easily been over 500 €, sometimes even around 1’000 €. Although, the market development has led to the situation, that in 2016 the potential income for one hour could have reached only around 100...200 € as shown in the figure 6.2.

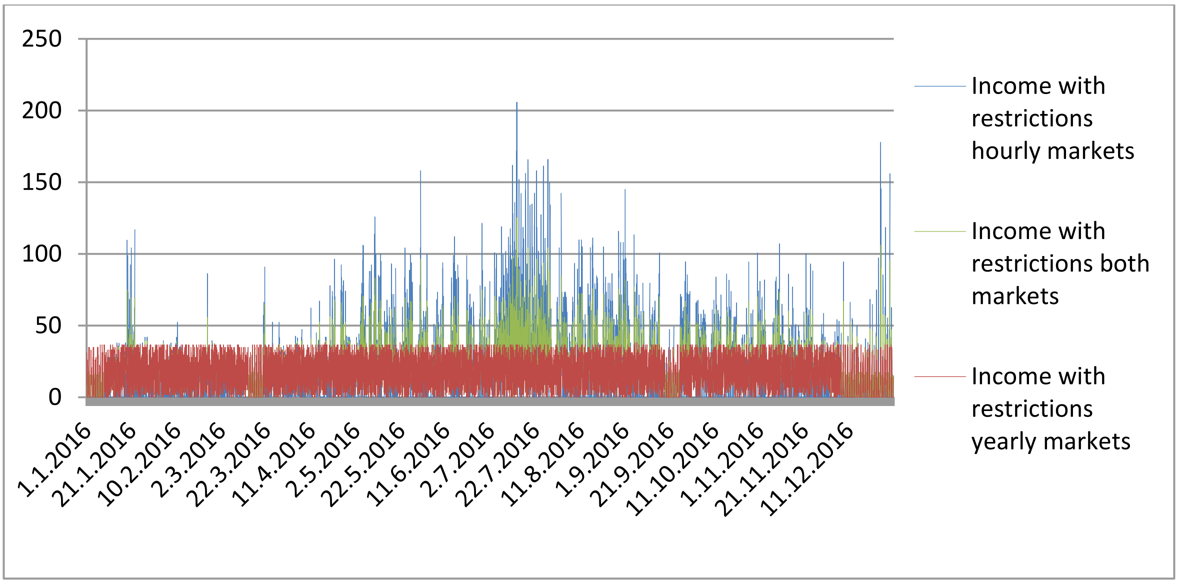


Figure 6.2 The calculated possible hourly income in the three different market participation types in the year 2016.

The individual simulation runs for the same capacity selling type, year and restriction settings gave relatively close results when comparing them with different simulation rounds. The differences between minimum and maximum values ranged from 2’000 € to 10’000 €. The resulted differences depend on the scenario and the simulated year.

The relative difference of the maximum and minimum yearly incomes ranged between 0.5 % and 2.2 % compared to the corresponding averages. Based on these results, it can be said that trying to time the reserves for the expensive hours and avoiding cheap ones isn’t that important, since the possible income doesn’t vary too greatly.

In reality, it is not possible to aim the highest capacity for the expensive hours, as the reserve capacity is offered to a closed auction. In general it can be said though, based on the figures 6.1 and 6.2 and the figures in the appendix C, that there are usually higher prices during the summer time than the rest of the year.

As clearly shown in the figure 6.3, bigger difference could be found in the possible income with and without restrictions of the important sales periods, when the simulations were done for the same year and with the same capacity selling type. The differences between the yearly income averages of with and without restrictions in different scenarios ranged between 7’500...14’000 € yearly. The more precise results of each simulation round and average yearly incomes are represented in the appendix B.

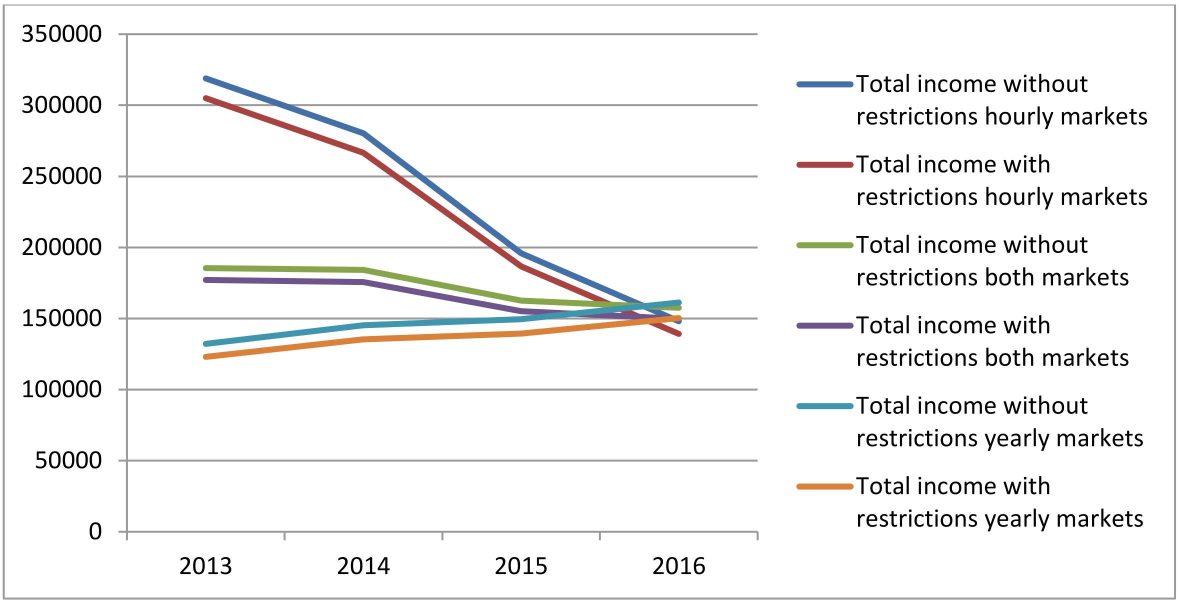


Figure 6.3 The development of the average income of each year based on the simulation.

The differences between the simulations with and without the restrictions were roughly 4...7 % of the corresponding total average income with the restrictions. Thus, the important sales period restrictions don't have a huge impact on the possible income either, but their impact is still negative.

As shown on the figure 6.3, the biggest differences are still between the different years and markets. The average income from the years 2013, 2014, 2015 and 2016 from the hourly markets would have been around 305'000 €, 267'000 €, 187'000 € and 139'000 €, respectively. The yearly average prices on the FCR-N hourly market have been 36.33, 31.93, 22.32 and 16.81 €/MW,h in 2013, 2014, 2015 and 2016, respectively. The differences in the income and the average market prices in different years suggest that the general price level defines the possible income more than the right timing of the offered capacity, as the average offered capacity in each year is around the same.

The clearest result of the simulation is that the possible income has come down dramatically on the hourly markets. At the same time the income from the yearly markets has been relatively stable. Actually the possible income from the yearly market has been increasing slightly from year to year during the observed period. This has lead to a situation that in 2016 it would have been more profitable to participate only the yearly markets instead of the hourly markets.

The most profitable option in 2016 would have been to participate only in the yearly markets, but participating in both of the markets would have generated almost the same income. The situation would have been this when the important sales period restrictions were taken into account. The difference would have been slightly greater, if there wouldn't have been any participation restrictions whatsoever.

Even though the differences between market participation models were quite small in 2016, this is a significant result. During the earlier years, participating in both of the markets has been always clearly more profitable than the yearly markets alone, but it has also been much less profitable than participation to the hourly markets alone.

7. Discussion

One might question, why the income of one year is calculated basically like a lottery with certain probabilities. The chosen model can be justified by the fact that the available capacity can't be completely known for each hour at this point, as it would require at least one year of field tests. Even if the tests were carried out, there would still be significant differences between the test year and other years as no year is alike with another one. In the context of a master's thesis, long term field tests are not possible and in practice these tests will be carried out during the first years of the microgrid in operation. The microgrid is therefore a system, that will be continuously developed based on the previous experiences.

The average of the offered capacity of every simulation round sets around 1100 kW with the maximum difference between the individual simulations being less than 2 %. The chosen random-number-method for the model doesn't overemphasize either the role of the expensive or the cheap hours. Additionally, the simulation was run ten times for each year and then the arithmetic averages were calculated from the results in order to minimize the influence of exceptional results of individual simulations. That means that the averages of the simulation rounds for each year should give rather good estimation of the expected income.

As shown in the results in the chapter 6, the possible income from the hourly markets alone has decreased. This was expected partly, as the yearly average prices of the hourly markets have sunk dramatically as well. At the same time, other options have proved to be relatively stable source of income and they have even become more profitable each year. This raises a question: Why has the average price and consequently the possible income changed then this dramatically in the hourly markets?

Naturally the supply and the demand define the price on the markets, but the average need of FCR-N capacity from the hourly market doesn't explain the drop in the price, since it has fluctuated without a clear correlation to the average price. Also the capacity acquisition from the yearly markets could explain the drop, but the capacity there has been relatively steady ranging around 71...75 MW between the years 2011 to 2015.

In 2016 the acquisition from the yearly markets was 89 MW. (Fingrid 2017v) The sudden volume increase in the yearly market can partially explain the price drop in 2016, because that year there were altogether 3060 hours when any capacity wasn't bought from the hourly markets. This is significantly higher than in 2015, when the amount was 1980. In 2013 and 2014 the amounts were between these two, setting at 2625 and 2663, respectively. Therefore, the amount of "no-purchase" hours cannot explain the price drop in any other year than 2016.

The price on the hourly market should have been higher in 2016, as the offers for the yearly markets have to be given first, and only the cheapest ones of them are accepted.

This should leave more expensive capacity to the hourly markets. On the other hand, the increased volume in the yearly market should decrease the volume needed to be bought from the hourly markets. However, the average volume bought from the hourly market in 2016 was practically the same as in 2013, even though it was around 25...30 % lower than in 2014 and 2015. (Fingrid 2017i)

Based on the presented reasons, the only logical option left is that some new reserve capacity has entered the markets and those are cheaper to operate as a reserve than the old ones. This assumption is supported by the number of hours with extremely high prices that have sunk every year since 2013. As an extremely high price qualifies here a price over 100 €/MW,h. The classified number of hours with the extremely high prices of years 2013...2016 are shown in the table 7.1.

Table 7.1. Number of hours with extremely high prices on the FCR-N hourly markets in the years 2013...2016. (Fingrid 2017i)

	= 0 €/MW,h	> 100 €/MW,h	> 200 €/MW,h	> 300 €/MW,h	> 400 €/MW,h	> 500 €/MW,h
2013	2492	352	71	31	24	2
2014	2663	130	31	15	3	2
2015	1980	40	5	2	2	0
2016	3126	1	0	0	0	0

As presented in the table 7.1, in 2013 there were 352 hours, when the FCR-N hourly market price was over 100 €/MW,h. From that situation the number has been steadily decreasing, leading to the situation that in 2016 there was only one hour, when the reserve price was over 100 €/MW,h.

As a conclusion it can be said, that the FCR-N reserve markets have clearly attracted new capacity to join them and lead to a situation where the hourly market prices have dropped dramatically since 2013. At the same time, the yearly market prices have increased, but not as much as the hourly market prices have dropped. This is most likely due to the fact that Fingrid decides alone how much capacity is allowed to enter the yearly markets and what is the highest acceptable price. Possibly some capacity that has earlier participated the yearly markets has moved to the hourly markets, but the information concerning this isn't transparent because of the nature and the rules of the markets.

From the perspective of Fingrid, the sinking of the prices is a good thing as the overall costs of the reserves decrease. For the reserve providers this means naturally lower income than earlier. For some actors on the market the frequency regulation may even become unprofitable. On the other hand, this can also be seen as a sign that the markets work properly and effectively by finding continuously cheaper alternatives.

Forecasting is naturally difficult, especially forecasting the future. That means that the results don't give any signal what the income will be in 5...10 years. During the next three years the market can be expected to stay relatively stable but of course there is no guarantee that this will be the case in reality.

The stable market estimation that has been made, is supported by the average price level of 2017. Until the end of July 2017, the average price on the FCR-N hourly market was higher than it was during the whole year of 2016, but still slightly lower than during the whole year of 2015 setting at 21.60 €/MW,h (Fingrid 2017i).

The total value of the project is approximately 6 million Euros. The payback period has been estimated to be 7...9 years. (MTV 2017) The Finnish Ministry of Economic Affairs and Employment has also granted to the project an energy investment subsidy worth 1’896’000 Euros (Ministry of Economic Affairs and Employment 2017b). The investment subsidy is around one third of the total investment. It is well in line with the support for new energy technologies, which can range 20...40 % of the investment (Ministry of Economic Affairs and Employment 2017a)

If only the income calculated in this thesis was considered, the payback period without the investment support for the whole project would be around 43 years with the price level of the FCR-N hourly market in 2016. With the price level of the FCR-N hourly market in 2013, the payback period would be only 20 years, but it’s still much longer than the official estimation. This is due to the fact, that in this thesis all benefits haven’t been taken into account. Such benefit is the solar power generation, for example.

Clearly, the payback period is strongly dependent on the market prices and their development. Naturally, the markets can develop in any possible way. The development cannot be really predicted further than the next few years. At this point it cannot even be known yet which resources are participating the markets in e.g. 5 years. Most likely there will be much more flexible energy consumption units than nowadays.

Even though in this thesis, the yearly benefits from the reserve response of the battery and the building technology have been calculated to be only around 139’000 € based on the price level of 2016, it has to be noted that the reserve response function is only one of the new functionalities taken into use in the project.

For example the benefits from the load shifting aspects and direct energy savings from change of the lighting haven’t been taken into account at all. Also the energy purchase saving, that can be gained with the power produced by the solar power plant, haven’t been calculated in this thesis either.

8. Conclusions

At the moment, hydropower, condensing power and CHP are the key players in the reserve markets, but it can be expected that different kind of consumption units will play greater part in the future. Will this change happen in three, in five or in ten years or even later, it cannot be predicted. The only sure thing is, that the demand response has come to play a stable and significant role.

As the conducted simulations of the expected income have shown, changing the building automation has a very high potential to be beneficial and profitable when the system becomes a real microgrid and operates as a power reserve. As the system consists of many individual units, the proofing of the committed regulation actions can be challenging. In fact, further studies are probably needed on the topic, how the proofing of the reserve responses should be done optimally.

The metering should be sufficient to do this and the meters should also be accurate enough. In most of the cases, this means that significant amount of new meters must be installed. As an extra-benefit from the additional metering is, that the processes inside the building become more transparent, which allows not only better demand response optimizations, when the project has been finished, but also better energy efficiency optimizations in the future.

An automatic microgrid control system will be needed for the solution, so the individual units can be controlled easily together and the separate regulation actions can be combined for proofing purposes. In a user-friendly case, one system would be able to do both as well as the communication towards Fingrid. Naturally, more than one system can be used, if it is found to be a better solution for the purpose.

The biggest risks are connected to the changes in the market environment, as the amount of yearly profits should be predicted for the investor. In a way, the Finnish reserve markets could be compared to the stock exchange markets: the investment to the automation is like buying shares and then the market development in the future defines the profits. The investment is also very likely to increase the value of the building, which secures a part of the investment.

As the financial risks are quite clearly connected to the market price development, the technical risks are mostly connected to the market requirements since the system should pass easily the current requirements. In this thesis it was assumed that the technical requirements for a reserve would be the same as they were in 2017. As it was noted in the chapter 2.2, the requirements and market rules are most likely changing during the coming years, but they cannot be taken into account yet in this thesis, since the future rules are not finalized.

That means, a small chance stays, that in some point the presented solution cannot participate in the markets due to technical requirements. However, the current estimation is that the microgrid solution doesn't have much of difficulties to fulfil the future requirements. When tested remotely, the control commands could be executed within few seconds. Rather hydropower and other big inertial power producers are facing problems in the future due to the long reaction times.

If the presented solution becomes more common and it can be scaled up to bigger units, it can potentially create a huge saving for the society. Firstly, it allows the complete integration of the weather-dependent renewables to the energy system, which makes it possible to produce more electricity with low marginal costs. That should sink the price of electricity from the current level, which would give a competitive edge for the society in comparison with the other countries.

Secondly, it reduces the need for investing to peak power and backup power plant. This is a great saving for the society, when there isn't a need to maintain expensive plants, that are just waiting silently for a command to turn on only on the coldest days of the winter. Some years the peak power plants might not even run at all, or they run only during the couple of peak hours.

Consequently, the demand response could also possibly cut the peak prices of electricity in the spot markets and the electricity price would stay roughly the same throughout the day. Naturally, there would be still some variation in the price of electricity between the hours and days, but the electricity consumers wouldn't have to fear for unexpected, extremely high peaks.

Industrial investors could make their investment decisions based on the assumption that the price of electricity would stay relatively stable. The factories can keep their processes running in the most efficient way instead of observing, which hours are cheaper and when it's not anymore profitable to operate.

When all is said and done, it can be stated that microgrids have a great potential to operate as a reserve. At the same time, they can generate an additional income for the property owners, maintain the crucial power balance in the energy system, create savings for the society by reducing the need to invest and maintain peak power plants and increase the security of supply. And all these, the microgrid can do cheaper, more efficiently and significantly faster than the power plants currently.

9. Bibliography

Baltic Connector. *Project purpose and objectives.* 2017. http://balticconnector.fi/en/the-project/ (accessed June 7th, 2017).

Bruch, Maximilian, and Martin Müller. "Calculation of the Cost-Effectiveness of a PV Battery System." *Energy Procedia* 46 (2014): 262-270.

Energiavirasto. *Tuotantotukijärjetelmän yhteenveto.* March 1st, 2016. http://www.energiavirasto.fi/documents/10179/0/Tukij%C3%A4rjestelm%C3%A4n+yhteenveto+1.3.2016.pdf/097614ac-0532-4741-9598-7f7912bfd2a2 (accessed March 2nd, 2017).

Epple, Bernd. "Energietechnik 3: Emissionsarme Kraftwerkstechnologien." Lecture slides, Energiesysteme und Energietechnik, Technische Universität Darmstadt, Darmstadt, 2015.

European Commission. *State aid: Commission approves aid for Finnish LNG terminal at Hamina.* March 18th, 2016. http://europa.eu/rapid/press-release_IP-16-923_en.htm (accessed June 7th, 2017).

Federal Energy Regulatory Commission. *Reports on Demand Response & Advanced Metering.* February 6th, 2017. https://www.ferc.gov/industries/electric/indus-act/demand-response/dem-res-adv-metering.asp (accessed May 30th, 2017).

Fennovoima. *Electricity and Vitality.* 2017. http://www.fennovoima.fi/en/fennovoima (accessed February 21st, 2017).

Fingrid. *Appendix 2 to the Yearly Agreement and Hourly Market Agreement for Frequency Controlled Normal Operation Reserve and Frequency Controlled Disturbance Reserve.* January 1st, 2017a. http://www.fingrid.fi/en/powersystem/Power%20system%20attachments/2017/Liite2%20-%20Taajuusohjattujen%20reservien%20ylläpidon%20sovellusohje%202017_eng.pdf (accessed June 13th, 2017).

—. *Appendix 3 to the Hourly Market Agreement for Frequency Controlled Normal Operation.* January 1st, 2017b. http://www.fingrid.fi/en/powersystem/Power%20system%20attachments/2017/Liite3%20-%20Taajuusohjattujen%20reservien%20ylläpidon%20tuntimarkkinasäännöt%202017_eng.pdf (accessed June 13th, 2017).

—. *Application instruction for the maintenance of frequency controlled reserves.* January 1st, 2017c. http://www.fingrid.fi/en/powersystem/Power%20system%20attachments/2017/Liite2%20-%20Taajuusohjattujen%20reservien%20ylläpidon%20sovellusohje%202017_eng.pdf (accessed September 1st, 2017).

—. *Automaattisen taajuudenhallintareservin sovellusohje.* August 8th, 2016a. http://www.fingrid.fi/fi/voimajarjestelma/voimajarjestelmaliitteet/Reservit/2016/Liite%201%20-%20Automaattisen%20taajuudenhallintareservin%20sovellusohje.pdf (accessed June 9th, 2017).

—. *Automaattisen taajuudenhallintareservin tuntimarkkinasopimus nro XX/2016.* August 8th, 2016b. http://www.fingrid.fi/fi/voimajarjestelma/voimajarjestelmaliitteet/Reservit/2016/aFRR%20sopimus%202016_pohja.pdf (accessed June 9th, 2017).

—. *Balancing power market.* January 1st, 2017d. http://www.fingrid.fi/en/customers/Balance%20services/management/powermarket/Pages/default.aspx (accessed August 27th, 2017).

—. *Balancing power price.* May 8th, 2017e. http://www.fingrid.fi/EN/ELECTRICITY-MARKET/BALANCING-POWER/BALANCING-POWER-PRICE/Pages/default.aspx (accessed May 10th, 2017).

—. *Cross-border transmission capacities – Russia 400 kV.* 2017f. http://www.fingrid.fi/en/electricity-market/cross-border-transmission/Pages/Russia-400-kV.aspx (accessed April 28th, 2017).

—. *Frequency containment reserves.* 2017g. http://www.fingrid.fi/en/electricity-market/reserves/reservetypes/containment/Pages/default.aspx (accessed May 5th, 2017).

—. *Frequency controlled disturbance reserve.* September 15th, 2017h. http://www.fingrid.fi/en/electricity-market/frequency-controlled-reserves/hourlytransactions/Pages/disturbancereserve.aspx (accessed September 15th, 2017).

—. *Frequency controlled normal operation reserve.* June 28th, 2017i. http://www.fingrid.fi/en/electricity-market/frequency-controlled-reserves/hourlytransactions/Pages/normaloperationreserve.aspx (accessed August 4th, 2017).

—. *Frequency restoration reserves.* 2017j. http://www.fingrid.fi/en/electricity-market/reserves/reservetypes/restoration/Pages/default.aspx (accessed May 10th, 2017).

—. *Hourly Market Agreement for No. XX Frequency Controlled Normal Operation Reserve and Frequency Controlled Disturbance Reserve.* January 1st, 2017k. http://www.fingrid.fi/en/powersystem/Power%20system%20attachments/2017/Taajuusohjattujen%20reservien%20tuntimarkkinasopimus%202017_pohja_eng.pdf (accessed May 30th, 2017).

Fingrid. *Johtokatu - tiekartta vihreään sähköjärjestelmään.* Helsinki: Fingrid, 2017l.

—. *Manual Frequency Restoration Reserve (FRR-M).* 2017m. http://www.fingrid.fi/en/electricity-market/reserves/acquiring/fastreserve/Pages/default.aspx (accessed May 10th, 2017).

—. *Negative regulating power price in Finland during last night.* May 5th, 2017n. http://www.fingrid.fi/en/news/announcements/Pages/Negative-regulating-power-price-in-Finland-during-last-night.aspx (accessed May 9th, 2017).

—. *Procurement of reserves.* 2017o. http://www.fingrid.fi/en/electricity-market/reserves/acquiring/Pages/default.aspx (accessed April 28th, 2017).

—. *Reserves.* 2017p. http://www.fingrid.fi/en/electricity-market/reserves/Pages/default.aspx (accessed April 27th, 2017).

—. "Reservipäivät 2017." Helsinki, May 17th-18th, 2017q.

—. *Reservipäivät 2017 automaattinen taajuudenhallintareservi (a frr) nyt ja tulevaisuudessa (id 52496).* May 18th, 2017r. https://www.slideshare.net/Fingrid/reservipivt-2017-automaattinen-taajuudenhallintareservi-a-frr-nyt-ja-tulevaisuudessa-id-52496?qid=e56d56cb-db8b-4bcd-b8ea-10d6fc6c6998&v=&b=&from_search=1 (accessed June 12th, 2017).

—. *Reservipäivät 2017 fingridin aggregointipilotit.* May 18th, 2017s. https://www.slideshare.net/Fingrid/reservipivt-2017-fingridin-aggregointipilotit-id-54410?qid=524f56b4-33f8-46ad-82e4-667c8338f63d&v=&b=&from_search=1 (accessed June 8th, 2017).

—. *Wind power generation.* May 10th, 2017t. http://www.fingrid.fi/en/electricity-market/load-and-generation/windpower/Pages/default.aspx (accessed May 10th, 2017).

—. *Volume of balancing power.* May 8th, 2017u. http://www.fingrid.fi/en/electricity-market/balancing-power/Pages/volume-of-balancing-power.aspx (accessed May 10th, 2017).

—. *Vuosimarkkinat.* 2017v. http://www.fingrid.fi/fi/sahkomarkkinat/taajuusohjatutreservit/toteutuneettuntikaupat/vuosihinnat/Sivut/default.aspx (accessed June 20th, 2017).

—. *Yearly Market Agreement for No. XX Frequency Controlled Normal Operation Reserve and Frequency Controlled Disturbance Reserve.* January 1st, 2017w. http://www.fingrid.fi/en/powersystem/Power%20system%20attachments/2017/Taajuusohjattujen%20reservien%20vuosisopimus%202017_eng.pdf (accessed May 30th, 2017).

Finlex. *Laki sähkön ja eräiden polttoaineiden valmisteverosta.* 4 19th, 2017. http://www.finlex.fi/fi/laki/ajantasa/1996/19961260?search%5Btype%5D=pika&search%5Bpika%5D=s%C3%A4hk%C3%B6vero (accessed April 27th, 2017).

Finsolar. *Aurinkosähköjärjestelmien hintatasot ja kannattavuus.* 2017. http://www.finsolar.net/aurinkoenergian-hankintaohjeita/aurinkosahkon-hinnat-ja-kannattavuus/ (accessed March 24, 2017).

Fortum. *Loviisa power plant.* 2017. http://www.fortum.com/en/energy-production/nuclear-power/loviisanpp/pages/default.aspx (accessed April 27th, 2017).

Jäppinen, Jonne, and Mikko Kuivaniemi, interview by Laaksonen Anssi, Makkonen Henri and Laakso Sami. *Demand response & Fingrid* (March 27th, 2017).

Kakkonen, Jukka. *EU:n päästökauppa. Selvitys EU:n päästökauppajärjestelmästä, päästöoikeuden hinnasta ja päästökauppajärjestelmään puuttumisesta.* Practical work, Espoo: Enegiateollisuus, 2013.

Keva. *Kauppakeskus Selloon rakennetaan älykäs aurinkoenergiajärjestelmä.* September 12th, 2017. https://www.keva.fi/uutiset-ja-artikkelit/kauppakeskus-selloon-rakennetaan-alykas-aurinkoenergiajarjestelma/ (accessed September 14th, 2017).

Lund, Peter. "The link between political decision-making and energy options: Assessing future role of renewable energy and energy efficiency in Finland." *Energy 32*, February 11th, 2007: 2271-2281.

Luoma, Jaakko. *Liike-, toimisto- ja koulurakennuksien sähkökuormat kysynnän jouston reserveinä.* M.Sc. Thesis, Tampere: Tampereen teknillinen yliopisto, 2015.

Manninen, Kreetta. *Rakennuksen kysyntäjoustomallinnuksen vaatimusten määritys.* M.Sc. Thesis, Lappeenranta: Lappeenranta University of Technology, 2017.

Ministry of Economic Affairs and Employment. *Maximum amount of aid.* January 1st, 2017a. http://tem.fi/en/maximum-amount-of-aid (accessed September 15th, 2017).

—. *Sellolle ja Lidlille tukea älykkäiden energiajärjestelmien rakentamiseen.* September 8th, 2017b. http://tem.fi/artikkeli/-/asset_publisher/sellolle-ja-lidlille-tukea-alykkaiden-energiajarjestelmien-rakentamiseen (accessed September 14th, 2017).

Motiva Oy & National Emergency Supply Agency. *Smart Energy Demand Coalition.* Helsinki: Motiva Oy, 2016.

Motiva. *Syöttötariffi.* January 12rh, 2017. http://www.motiva.fi/toimialueet/uusiutuva_energia/uusiutuva_energia_suomessa/uusiutuvan_energian_tuet/syottotariffi (accessed March 2nd, 2017).

MTV. *Espoolaiseen kauppakeskukseen suuri sähkövarasto: Parkkihalliin 50 000 kiloa painava akku.* October 2nd, 2017. https://www.mtv.fi/uutiset/kotimaa/artikkeli/espoolaiseen-kauppakeskukseen-suuri-sahkovarasto-parkkihalliin-50-000-kiloa-painava-akku/6603214#gs.PA5IgoE (accessed October 4th, 2017).

Nord Pool. *About us.* 2017a. http://www.nordpoolspot.com/About-us/ (accessed March 29, 2017).

—. *Elspot prices.* 2017b. http://www.nordpoolspot.com/Market-data1/Elspot/Area-Prices/ALL1/Yearly/?view=table (accessed March 29th, 2017).

—. *Fees: Nordic, Baltics and Germany.* 2017c. http://www.nordpoolspot.com/TAS/Fees/Nordic-Baltic/ (accessed May 12th, 2017).

—. *Intraday market.* 2017d. http://www.nordpoolspot.com/How-does-it-work/Intraday-market/ (accessed May 12th, 2017).

—. *Intraday trading.* 2017e. http://www.nordpoolspot.com/TAS/nord-pool-spot-intraday/ (accessed May 12th, 2017).

—. *Price calculation.* 2017f. http://www.nordpoolspot.com/TAS/Day-ahead-market-Elspot/Price-calculation/ (accessed March 2nd, 2017).

Ojanen, Heikki. *Commissioning of frequency controlled reserve.* M.Sc. Thesis, Espoo: Aalto University School of Electrical Engineering, 2016.

OPEC. *Fossil fuels and the future – OPEC Bulletin Commentary April 2016.* 2016. http://www.opec.org/opec_web/en/press_room/3467.htm (accessed March 2nd, 2017).

Realprojekti Oy. *Shopping Center Sello to begin building a virtual power plant for properties in Finland.* September 7th, 2017. http://www.realprojekti.fi/files/realprojekti/Tiedotteet%20ja%20liitteet/Siemens_Sello%20pressrelease%2007092017.pdf (accessed September 14th, 2017).

Sello. *Kierrätys ja ympäristö.* 2017. http://www.sello.fi/kierratys-ja-ymparisto (accessed May 3rd, 2017).

Smart Energy Demand Coalition. *Mapping Demand Response in Europe Today.* Brussels: Smart Energy Demand Coalition, 2015.

Suomen tuulivoimayhdistys. *Tuulivoima Suomessa.* 2017. http://www.tuulivoimayhdistys.fi/tietoa-tuulivoimasta/tietoa-tuulivoimasta/tuulivoima-suomessa-ja-maailmalla/tuulivoima-suomessa (accessed March 2nd, 2017).

Talouselämä. *Kauppakeskus Sello varautuu sähkön kysyntäpiikkeihin 2 000 aurinkopaneelilla – syynä sähköautojen lataaminen.* September 9th, 2017. http://www.talouselama.fi/uutiset/kauppakeskus-sello-varautuu-sahkon-kysyntapiikkeihin-2-000-aurinkopaneelilla-syyna-sahkoautojen-lataaminen-6675588 (accessed September 14th, 2017).

Taloussanomat. *Säätösähkön hinta kävi miinuksella – voi yleistyä Suomessa.* May 8th, 2017. http://www.is.fi/taloussanomat/porssiuutiset/art-2000005202458.html (accessed May 10th, 2017).

Tekes. *Energy aid.* 2017. https://www.tekes.fi/en/funding/SME/energy-aid/ (accessed May 4th, 2017).

Tekniikka & talous. *Kauppakeskus saa virtuaalisen voimalaitoksen – suomalainen tekniikka kiinnostaa muuallakin.* September 7th, 2017. http://www.tekniikkatalous.fi/tekniikka/energia/kauppakeskus-saa-virtuaalisen-voimalaitoksen-suomalainen-tekniikka-kiinnostaa-muuallakin-6674516 (accessed September 14th, 2017).

Teollisuuden Voima Oyj. *New operating license applied for Olkiluoto 1 and 2 plant units.* January 26th, 2017. http://www.tvo.fi/news/1829 (accessed April 27th, 2017).

Tilastokeskus. *Electricity supply and production, GWh.* 4 27th, 2017. http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__ene__salatuo/010_salatuo_tau_101.px/?rxid=6c729b64-cb5b-4d45-9fb7-b76910cbdb73 (accessed April 28th, 2017).

—. *Uusiutuvilla energialähteillä tuotetun sähkön määrä ennätystasolla.* November 2nd, 2016. http://www.stat.fi/til/salatuo/2015/salatuo_2015_2016-11-02_tie_001_fi.html (accessed March 29th, 2017).

Trading Economics. *Coal historical prices.* 2017. http://www.tradingeconomics.com/commodity/coal (accessed March 29th, 2017).

Yleisradio. *TVO: Olkiluoto 3 valmistuu varmasti – suurin huoli sen jälkeinen aika.* November 16th, 2016. http://yle.fi/uutiset/3-9297407 (accessed February 22nd, 2017).

ÅF-Consult Ltd. *Energiamarkkinaskenaariot vuosille 2020-2050.* Espoo: Suomen tuulivoimayhdistys ry, 2016.

Appendix A. Formulas of the Simulation

Here only the first two rows are represented as an example how the simulation was made. The prices and volumes of the FCR-N market are available online (Fingrid 2017i).

	A	B	C	D	E	F	G	H
1	**Date**	**Time (EET)**	**The price of FCR-N on hourly markets (€/MW)**	**The volume of FCR-N on hourly markets (MW)**	**Winter sale**	**Sembalot spring**	**Sembalot autumn**	**Christmas time**
2	1.1.2015	0:00	0,00	0,00	=IF(OR(B2=TIME(21;0;0);B2=TIME(22;0;0);B2=TIME(23;0;0);B2=TIME(0;0;0);B2=TIME(1;0;0);B2=TIME(2;0;0);B2=TIME(3;0;0);B2=TIME(4;0;0);B2=TIME(5;0;0);B2=TIME(6;0;0);B2=TIME(7;0;0));1;IF(OR(A2=DATE(2015;1;1);A2=DATE(2015;1;2);A2=DATE(2015;1;3);A2=DATE(2015;1;4);A2=DATE(2015;1;5);A2=DATE(2015;1;6);A2=DATE(2015;1;7);A2=DATE(2015;1;8));0;1))	=IF(OR(B2=TIME(21;0;0);B2=TIME(22;0;0);B2=TIME(23;0;0);B2=TIME(0;0;0);B2=TIME(1;0;0);B2=TIME(2;0;0);B2=TIME(3;0;0);B2=TIME(4;0;0);B2=TIME(5;0;0);B2=TIME(6;0;0);B2=TIME(7;0;0));1;IF(OR(A2=DATE(2015;3;14);A2=DATE(2015;3;15);A2=DATE(2015;3;16);A2=DATE(2015;3;17);A2=DATE(2015;3;18);A2=DATE(2015;3;19);A2=DATE(2015;3;20));0;1))	=IF(OR(B2=TIME(21;0;0);B2=TIME(22;0;0);B2=TIME(23;0;0);B2=TIME(0;0;0);B2=TIME(1;0;0);B2=TIME(2;0;0);B2=TIME(3;0;0);B2=TIME(4;0;0);B2=TIME(5;0;0);B2=TIME(6;0;0);B2=TIME(7;0;0));1;IF(OR(A2=DATE(2015;9;12);A2=DATE(2015;9;13);A2=DATE(2015;9;14);A2=DATE(2015;9;15);A2=DATE(2015;9;16);A2=DATE(2015;9;17);A2=DATE(2015;9;8));0;1))	=IF(OR(B2=TIME(21;0;0);B2=TIME(22;0;0);B2=TIME(23;0;0);B2=TIME(0;0;0);B2=TIME(1;0;0);B2=TIME(2;0;0);B2=TIME(3;0;0);B2=TIME(4;0;0);B2=TIME(5;0;0);B2=TIME(6;0;0);B2=TIME(7;0;0));1;IF(OR(A2=DATE(2015;12;8);A2=DATE(2015;12;9);A2=DATE(2015;12;10);A2=DATE(2015;12;11);A2=DATE(2015;12;12);A2=DATE(2015;12;13);A2=DATE(2015;12;14);A2=DATE(2015;12;15);A2=DATE(2015;12;16);A2=DATE(2015;12;17);A2=DATE(2015;12;18);A2=DATE(2015;12;19);A2=DATE(2015;12;20);A2=DATE(2015;12;21);A2=DATE(2015;12;22);A2=DATE(2015;12;23);A2=DATE(2015;12;24);A2=DATE(2015;12;25);A2=DATE(2015;12;26);A2=DATE(2015;12;27);A2=DATE(2015;12;28);A2=DATE(2015;12;29);A2=DATE(2015;12;30);A2=DATE(2015;12;31));0;1))

	I	J	K	L	M	N	O	P	Q	R
1	**Capacity of Sello**	**Offered capacity**	**Chance of rejection**	**Offer accepted/rejected**	**Income with restrictions hourly markets**	**Income without restrictions hourly markets**	**Income with restrictions yearly markets**	**Income without restrictions yearly markets**	**Income with restrictions both markets**	**Income without restrictions both markets**
2	=RANDBETWEEN(0;2200)	=ROUNDDOWN(I2;-2)	=IF(D2=0;0;RANDBETWEEN(0;20))	=IF(K2=0;0;1)	=E2*F2*G2*H2*C2*J2*L2/1000	=C2*J2*L2/1000	=E2*F2*G2*H2*J2*16,21/1000	=J2*16,21/1000	=IF(J2>1000;E2*F2*G2*H2/1000*(1000*16,21+(J2-1000)*C2*L2);J2*16,21/1000)	=IF(J2>1000;1/1000*(1000*16,21+(J2-1000)*C2*L2);J2*16,21/1000)

	S	T	U	V	W	X
1	**Total income with restrictions hourly markets**	**Total income without restrictions hourly markets**	**Total income with restrictions yearly markets**	**Total income without restrictions yearly markets**	**Total income with restrictions both markets**	**Total income without restrictions both markets**
2	=SUM(M2:M8785)	=SUM(N2:N8785)	=SUM(O2:O8785)	=SUM(P2:P8785)	=SUM(Q2:Q8785)	=SUM(R2:R8785)

Appendix B. Results of the Simulation Rounds

2013	Total income with restrictions hourly markets	Total income without restrictions hourly markets	Total income with restrictions yearly markets	Total income without restrictions yearly markets	Total income with restrictions both markets	Total income without restrictions both markets
1	302 282 €	316252	122 436 €	131683	175 971 €	184253
2	300 774 €	314127	124 215 €	133198	176 279 €	183907
3	305 730 €	319554	123 203 €	132157	178 926 €	186926
4	306 283 €	319375	123 421 €	132404	176 676 €	184524
5	306 677 €	320247	122 214 €	131337	178 742 €	186951
6	301 648 €	316759	122 074 €	131607	174 209 €	183546
7	311 013 €	324812	124 045 €	133116	180 010 €	188406
8	307 654 €	321918	123 701 €	133083	178 285 €	186932
9	304 655 €	318547	122 426 €	131627	175 231 €	183636
10	303 005 €	317235	122 438 €	131647	176 933 €	185563
Min	300 774 €	314 127 €	122 074 €	131 337 €	174 209 €	183 546 €
Max	311 013 €	324 812 €	124 215 €	133 198 €	180 010 €	188 406 €
AVG	304 972 €	318 882 €	123 017 €	132 186 €	177 126 €	185 464 €

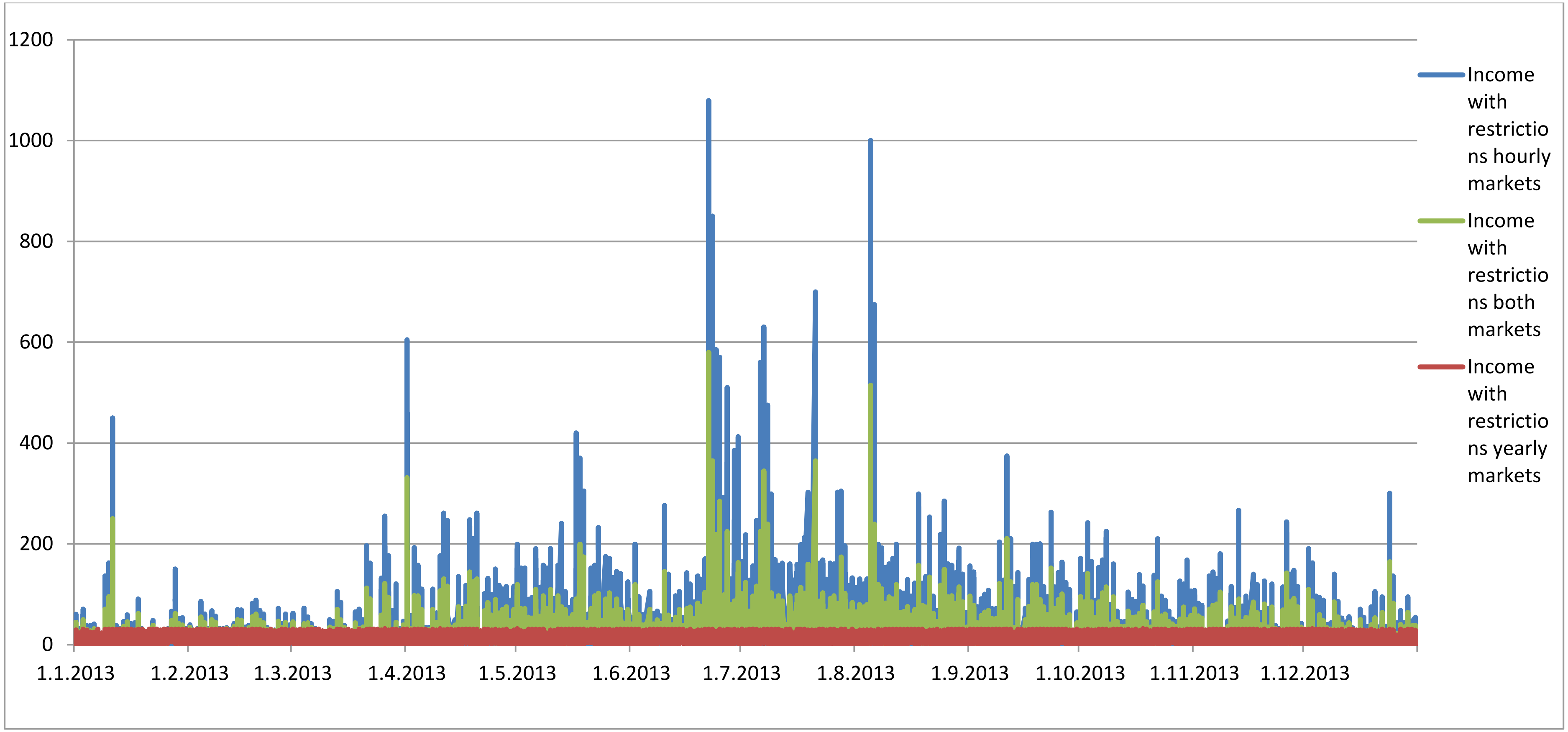
2014	Total income with restrictions hourly markets	Total income without restrictions hourly markets	Total income with restrictions yearly markets	Total income without restrictions yearly markets	Total income with restrictions both markets	Total income without restrictions both markets
1	271236,847	284444,967	136058,54	146154,74	179025,222	187885,447
2	263488,081	277862,045	135099,48	145115,1	173127,813	181768,273
3	265277,913	279621,11	134762,94	144813,32	174619,975	183578,622
4	272571,201	286175,734	135763,08	145585,94	178705,333	187324,328
5	269937,558	283931,855	135943,2	146303,26	178005,015	187128,762
6	262423,9	275849,514	135197,44	145153,02	173618,215	181942,443
7	265112,419	279060,212	134437,46	144527,34	174290,414	183156,777
8	266634,3	280458,854	135323,84	145328,4	174844,346	183581,93
9	267333,8	280738,822	135740,96	145780,28	175686,409	184273,831
10	262650,656	275633,912	134873,54	144465,72	173376,055	181025,132
Min	262 424 €	275 634 €	134 437 €	144 466 €	173 128 €	181 025 €
Max	272 571 €	286 176 €	136 059 €	146 303 €	179 025 €	187 885 €
AVG	266 667 €	280 378 €	135 320 €	145 323 €	175 530 €	184 167 €

2015	Total income with restrictions hourly markets	Total income without restrictions hourly markets	Total income with restrictions yearly markets	Total income without restrictions yearly markets	Total income with restrictions both markets	Total income without restrictions both markets
1	186138,013	195453,582	138344,245	148277,733	154025,678	161384,42
2	188656,019	197875,342	140490,449	150589,279	156083,061	163684,073
3	187360,712	196722,721	138227,533	148640,837	155121,224	162865,566
4	185581,045	194588,346	139240,658	149219,534	154763,385	161993,442
5	187292,575	196915,731	139362,233	149733,391	154782,762	162591,135
6	186101,135	195232,02	140735,22	150748,137	155835,845	163261,233
7	186376,564	195802,746	139310,361	149689,624	154873,012	162616,029
8	187895,439	197845,748	138785,157	149154,694	155269,094	163179,216
9	186478,029	195378,461	139167,713	149315,173	155728,017	162970,303
10	184734,918	194060,06	140328,349	150462,841	154247,484	161724,731
Min	184 735 €	194 060 €	138 228 €	148 278 €	154 026 €	161 384 €
Max	188 656 €	197 875 €	140 735 €	150 748 €	156 083 €	163 684 €
AVG	186 661 €	195 987 €	139 399 €	149 583 €	155 073 €	162 627 €

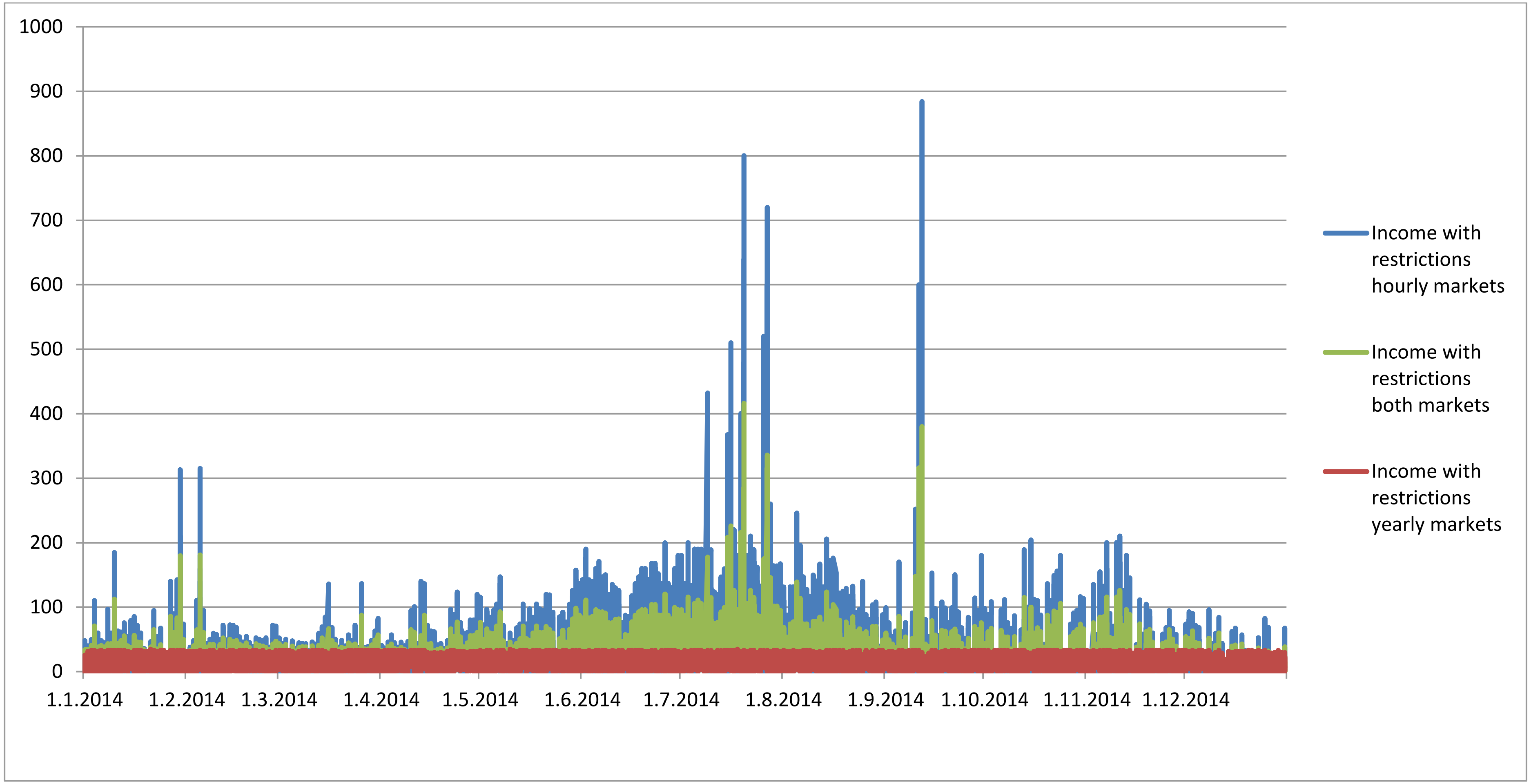
2016	Total income with restrictions hourly markets	Total income without restrictions hourly markets	Total income with restrictions yearly markets	Total income without restrictions yearly markets	Total income with restrictions both markets	Total income without restrictions both markets
1	140026,863	148913,916	151562,71	162580,86	150818,086	158608,036
2	139023,385	147976,643	149487,988	160324,97	149613,65	157126,023
3	140955,497	150135,074	151383,284	162875,258	151128,022	159214,494
4	138080,072	146438,502	150874,62	161459,012	150016,17	157430,37
5	140400,902	149343,009	150352,02	160979,962	150066,481	157789,853
6	138456,075	147708,115	149709,222	160967,768	149193,381	157304,896
7	139361,762	148195,257	151754,33	162580,86	150400,823	158115,793
8	141044,18	150010,312	150951,268	161870,124	150658,167	158600,304
9	137825,436	146761,165	149197,074	160013,152	149310,86	156769,11
10	136621,37	145281,615	147770,376	158729,298	146935,022	154468,387
Min	136 621 €	145 282 €	147 770 €	158 729 €	146 935 €	154 468 €
Max	141 044 €	150 135 €	151 754 €	162 875 €	151 128 €	159 214 €
AVG	139 180 €	148 076 €	150 304 €	161 238 €	149 814 €	157 543 €

Appendix C. Potential hourly income of years 2013-2016

2013



2014


1000
900
800
700
600
500
400
300
200
100
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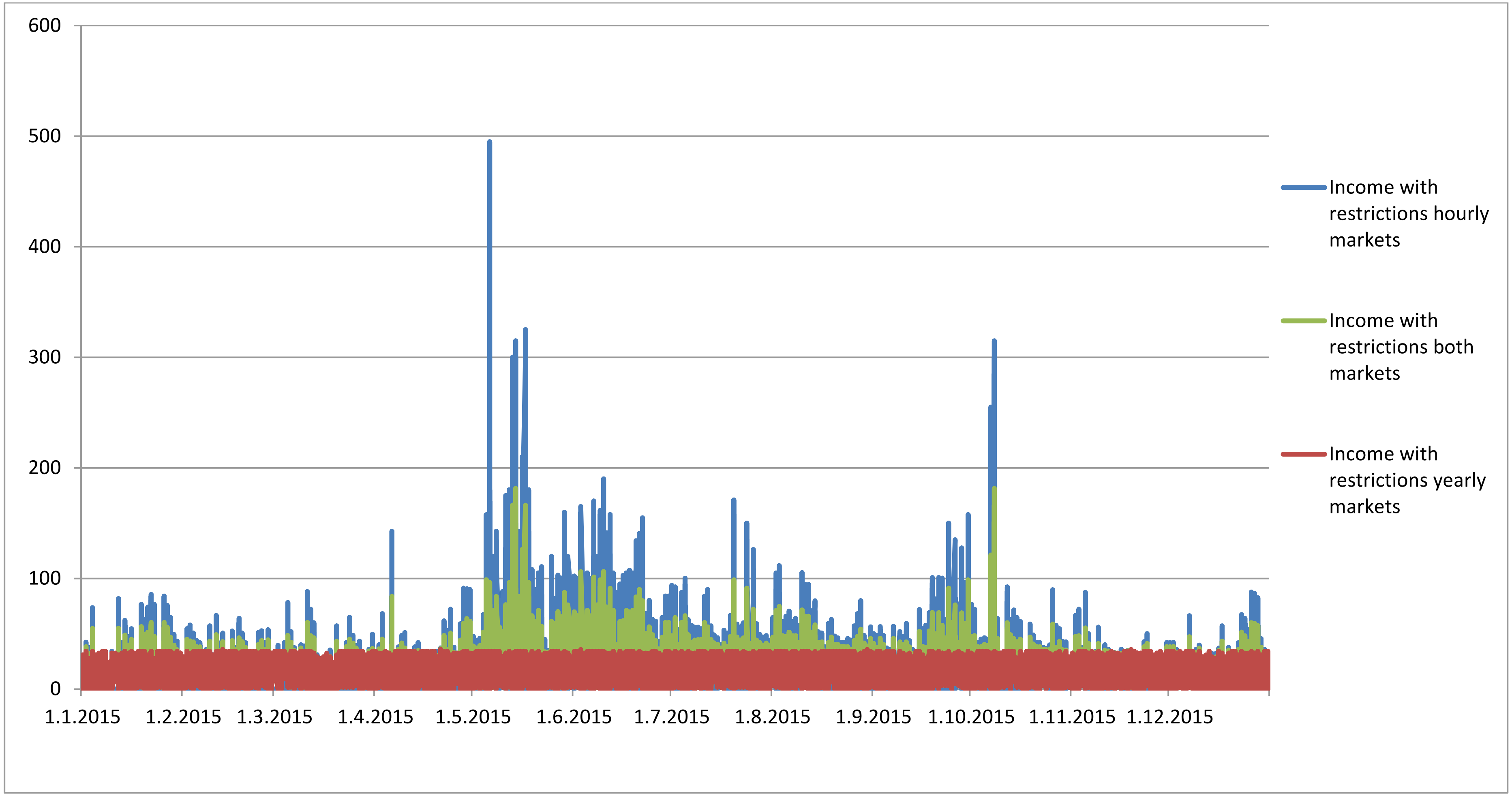
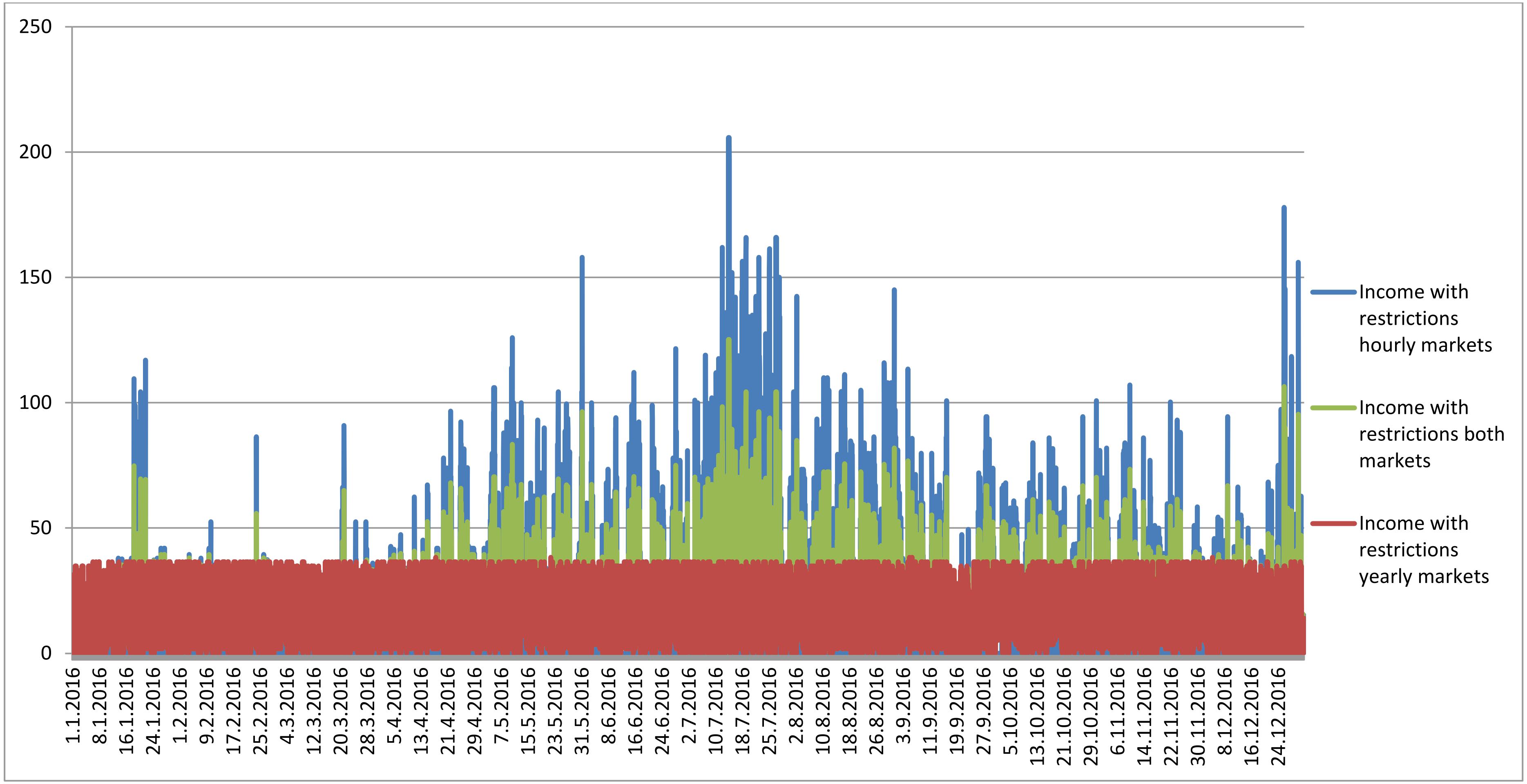
1.1.2014
1.2.2014
1.3.2014
1.4.2014
1.5.2014
1.6.2014
1.7.2014
1.8.2014
1.9.2014
1.10.2014
1.11.2014
1.12.2014
Income with restrictions hourly markets
Income with restrictions both markets
Income with restrictions yearly markets

2015



600
500
400
300
200
100
0
1.1.2015
1.2.2015
1.3.2015
1.4.2015
1.5.2015
1.6.2015
1.7.2015
1.8.2015
1.9.2015
1.10.2015
1.11.2015
1.12.2015
Income with restrictions hourly markets
Income with restrictions both markets
Income with restrictions yearly markets

2016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200
150
100
50
0
1.1.2016
8.1.2016
16.1.2016
24.1.2016
1.2.2016
9.2.2016
17.2.2016
25.2.2016
4.3.2016
12.3.2016
20.3.2016
28.3.2016
5.4.2016
13.4.2016
21.4.2016
29.4.2016
7.5.2016
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13.10.2016
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29.10.2016
6.11.2016
14.11.2016
22.11.2016
30.11.2016
8.12.2016
16.12.2016
24.12.2016
Income with restrictions hourly markets
Income with restrictions both markets
Income with restrictions yearly markets

Appendix D. Microgrid units

#	Description of the unit	Way of control	Nominal power of the unit (kW)	Min. (%)	Max (%)	Operating hours	Power limits during the operating hours
1	Ventilation unit	% of the dimensioning pressure	**2,85**	20 %	100 %	Mon-Sun 7:00- 23:20	50 -100%
2	Ventilation unit	% of the dimensioning pressure	**2,12**	20 %	100 %	Mon-Sun 7:00- 23:20	50 -100%
3	Ventilation unit	% of the dimensioning pressure	**1,94**	20 %	100 %	Mon-Sun 6:00-23:30	50-100%
4	Ventilation unit	% of the dimensioning pressure	**1,76**	20 %	100 %	Mon-Sun 6:00-23:30	50-100%
5	Ventilation unit	% of the dimensioning pressure	**6,44**	20 %	100 %	Mon-Sun7:00- 23:20	50-100%
6	Ventilation unit	% of the dimensioning pressure	**6,2**	20 %	100 %	Mon-Sun 7:00- 23:20	50-100%
7	Ventilation unit	% of the dimensioning pressure	**6,17**	20 %	100 %	Mon-Sun 7:00- 23:20	50-100%
8	Ventilation unit	% of the dimensioning pressure	**3,49**	20 %	100 %	Mon-Sun 7:00- 23:20	50-100%
9	Ventilation unit	% of the dimensioning pressure	**1,85**	20 %	100 %	Mon-Fri 5:00-21:30, Sat 5:00-18:20	50-100%
10	Ventilation unit	% of the dimensioning pressure	**1,49**	20 %	100 %	Mon-Fri 5:00-21:30, Sat 5:00-18:20	50-100%
11	Ventilation unit	% of the dimensioning pressure	**5,91**	20 %	100 %	Mon-Sat 7:00-22:00, Sun 8:45-22:00	50-100%
12	Ventilation unit	% of the dimensioning pressure	**3,96**	20 %	100 %	Mon-Sat 7:00-22:00, Sun 8:45-22:00	50-100%
13	Ventilation unit	% of the dimensioning pressure	**10,14**	20 %	100 %	Mon-Fri 5:00-23:15, Sat-Sun 7:00-23:15	50-100%
14	Ventilation unit	% of the dimensioning pressure	**7**	20 %	100 %	Mon-Fri 5:00-23:15, Sat-Sun 7:00-23:15	50-100%
15	Ventilation unit	% of the dimensioning pressure	**5,54**	20 %	100 %	Mon-Sat 7:00-23:15, Sun 9:00-23:15	50-100%
16	Ventilation unit	% of the dimensioning pressure	**4,15**	20 %	100 %	Mon-Sat 7:00-23:15, Sun 9:00-23:15	50-100%
17	Ventilation unit	% of the dimensioning pressure	**5,29**	20 %	100 %	Mon-Sat 7:00-23:15, Sun 9:00-23:15	50-100%
18	Ventilation unit	% of the dimensioning pressure	**3,67**	20 %	100 %	Mon-Sat 7:00-23:15, Sun 9:00-23:15	50-100%
19	Ventilation unit	% of the dimensioning pressure	**4,81**	20 %	100 %	Mon-Sat 7:00-23:10, Sun 8:30-23:15	50-100%
20	Ventilation unit	% of the dimensioning pressure	**4,27**	20 %	100 %	Mon-Sat 7:00-23:10, Sun 8:30-23:15	50-100%
21	Ventilation unit	% of the dimensioning pressure	**3,36**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
22	Ventilation unit	% of the dimensioning pressure	**2**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
23	Ventilation unit	% of the dimensioning pressure	**4,25**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%

24	Ventilation unit	% of the dimensioning pressure	**3,82**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
25	Ventilation unit	% of the dimensioning pressure	**9,89**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
26	Ventilation unit	% of the dimensioning pressure	**8,88**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
27	Ventilation unit	% of the dimensioning pressure	**6,64**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
28	Ventilation unit	% of the dimensioning pressure	**5,61**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
29	Ventilation unit	% of the dimensioning pressure	**6,08**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
30	Ventilation unit	% of the dimensioning pressure	**5,56**	20 %	100 %	Mon-Fri 7:00-22:20, Sat 7:00-21:20, Sun 9:00-21:20	50-100%
31	Ventilation unit	% of the dimensioning pressure	**9,89**	20 %	100 %	Mon-Fri 7:00-21:15, Sat 9:00-18:15, Sun 11:00-18:15	50-100%
32	Ventilation unit	% of the dimensioning pressure	**8,88**	20 %	100 %	Mon-Fri 7:00-21:15, Sat 9:00-18:15, Sun 11:00-18:15	50-100%
33	Ventilation unit	% of the dimensioning pressure	**8**	20 %	100 %	Mon-Fri 7:00-21:15, Sat 9:00-18:15, Sun 11:00-18:15	50-100%
34	Ventilation unit	% of the dimensioning pressure	**7**	20 %	100 %	Mon-Fri 7:00-21:15, Sat 9:00-18:15, Sun 11:00-18:15	50-100%
35	Ventilation unit	% of the dimensioning pressure	**3,91**	20 %	100 %	Mon 8:00-22:00, Tue-Thu 8:00-24:00, Fri 8:00-Sat 04:00, Sat 8:00-Sun 04:00, Sun 11:00-22:00	50-100%
36	Ventilation unit	% of the dimensioning pressure	**3,57**	20 %	100 %	Mon 8:00-22:00, Tue-Thu 8:00-24:00, Fri 8:00-Sat 04:00, Sat 8:00-Sun 04:00, Sun 11:00-22:00	50-100%
37	Ventilation unit	% of the dimensioning pressure	**3,99**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:15, Sun 11:30-18:15	50-100%
38	Ventilation unit	% of the dimensioning pressure	**3,46**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:15, Sun 11:30-18:15	50-100%
39	Ventilation unit	% of the dimensioning pressure	**7,13**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 8:30-20:15, Sun 11:30-18:15	30-50%
40	Ventilation unit	% of the dimensioning pressure	**5,94**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 8:30-20:15, Sun 11:30-18:15	30-50%
41	Ventilation unit	% of the dimensioning pressure	**2,16**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:20, Sun 10:00-18:20	50-100%
42	Ventilation unit	% of the dimensioning pressure	**2,11**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:20, Sun 10:00-18:20	50-100%
43	Ventilation unit	% of the dimensioning pressure	**8,84**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:00, Sun 10:00-18:20	40-100%
44	Ventilation unit	% of the dimensioning pressure	**7,08**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:00, Sun 11:00-18:20	40-100%
45	Ventilation unit	% of the dimensioning pressure	**6,42**	20 %	100 %	Mon-Fri 8:00-21:15, Sat 8:00-20:15, Sun 11:00-18:15	40-100%
46	Ventilation unit	% of the dimensioning pressure	**5,64**	20 %	100 %	Mon-Fri 8:00-21:15, Sat 8:00-20:15, Sun 11:00-18:15	40-100%
47	Ventilation unit	% of the dimensioning pressure	**5,98**	20 %	100 %	Mon-Fri 9:99-21:10, Sat 9:00-20:00, Sun 11:30-18:30	50-100%
48	Ventilation unit	% of the dimensioning pressure	**5,32**	20 %	100 %	Mon-Fri 9:99-21:10, Sat 9:00-20:00, Sun 11:30-18:30	50-100%
49	Ventilation unit	% of the dimensioning pressure	**8,48**	20 %	100 %	Mon-Fri 5:30-22:00, Sat 5:30-20:15, Sat 8:00-18:15	50-100%
50	Ventilation unit	% of the dimensioning pressure	**7,7**	20 %	100 %	Mon-Fri 5:30-22:00, Sat 5:30-20:15, Sat 8:00-18:15	50-100%
51	Ventilation unit	% of the dimensioning pressure	**2,95**	20 %	100 %	Mon-Fri 8:00-22:00, Sat 8:00-21:00, Sun 9:00-18:30	30-100%
52	Ventilation unit	% of the dimensioning pressure	**1,84**	20 %	100 %	Mon-Fri 8:00-22:00, Sat 8:00-21:00, Sun 9:00-18:30	30-100%
53	Ventilation unit	% of the dimensioning pressure	**4,47**	20 %	100 %	Mon-Fri 7:00-21:20, Sat 7:00-20:20, Sun 9:00-18:20	50-100%
54	Ventilation unit	% of the dimensioning pressure	**5,1**	20 %	100 %	Mon-Fri 7:00-21:20, Sat 7:00-20:20, Sun 9:00-18:20	50-100%

55	Ventilation unit	% of the dimensioning pressure	**5,4**	20 %	100 %	Mon-Fri 8:00-21:15, Sat 8:00-20:00, Sun 11:30-18:20	30-80%
56	Ventilation unit	% of the dimensioning pressure	**3,72**	20 %	100 %	Mon-Fri 8:00-21:15, Sat 8:00-20:00, Sun 11:30-18:20	30-80%
57	Ventilation unit	% of the dimensioning pressure	**8,8**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:30-18:10	40-100%
58	Ventilation unit	% of the dimensioning pressure	**2,47**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:30-18:10	40-100%
59	Ventilation unit	% of the dimensioning pressure	**4,11**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:00-18:10	50-80%
60	Ventilation unit	% of the dimensioning pressure	**2,24**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:00-18:10	50-80%
61	Ventilation unit	% of the dimensioning pressure	**4,12**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:00-18:10	50-80%
62	Ventilation unit	% of the dimensioning pressure	**3,32**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:00-18:10	50-80%
63	Ventilation unit	% of the dimensioning pressure	**7,25**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:00, Sun 11:30-18:20	50-100%
64	Ventilation unit	% of the dimensioning pressure	**4,7**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:00, Sun 11:30-18:20	50-100%
65	Ventilation unit	% of the dimensioning pressure	**6,92**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:00, Sun 11:30-18:20	50-100%
66	Ventilation unit	% of the dimensioning pressure	**6,28**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:00, Sun 11:30-18:20	50-100%
67	Ventilation unit	% of the dimensioning pressure	**7,58**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:20, Sun 11:30-18:20	30-100%
68	Ventilation unit	% of the dimensioning pressure	**7,18**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:20, Sun 11:30-18:20	30-100%
69	Ventilation unit	% of the dimensioning pressure	**7,56**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:15, Sun 11:30-18:15	40-100%
70	Ventilation unit	% of the dimensioning pressure	**10,36**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:15, Sun 11:30-18:15	40-100%
71	Ventilation unit	% of the dimensioning pressure	**5,49**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:20, Sun 11:0018:15	50-100%
72	Ventilation unit	% of the dimensioning pressure	**4,42**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:20, Sun 11:00-18:15	50-100%
73	Ventilation unit	% of the dimensioning pressure	**5,64**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:30-18:15	30-100%
74	Ventilation unit	% of the dimensioning pressure	**4,79**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:30-18:15	30-100%
75	Ventilation unit	% of the dimensioning pressure	**8,3**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:30-18:15	50-80%
76	Ventilation unit	% of the dimensioning pressure	**6,47**	20 %	100 %	Mon-Fri 9:00-21:00, Sat 9:00-20:10, Sun 11:30-18:15	50-80%
77	Ventilation unit	% of the dimensioning pressure	**5,68**	20 %	100 %	Mon-Fri 8:30-21:00, Sat 8:30-20:00, Sun 11:30-18:20	50-100%
78	Ventilation unit	% of the dimensioning pressure	**4,07**	20 %	100 %	Mon-Fri 8:30-21:00, Sat 8:30-20:00, Sun 11:30-18:20	50-100%
79	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Sat 8:00-21:00, Sun 11:30-21:00	20-100%
80	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Sat 8:00-21:00, Sun 11:30-21:00	20-100%
81	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Sat 8:00-21:00, Sun 11:30-21:00	20-100%
82	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Sat 8:00-21:00, Sun 11:30-21:00	20-100%
83	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 7:30-21:15, Sun 12:00-21:15	20-100%
84	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Sat 7:30-21:30, Sun 11:00-21:30	20-100%
85	Ventilation unit	Fan speed %	**0**	20 %	100 %		20-100%
86	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 8:00-21:15, Sat 8:00-18:30, Sun 11:00-21:30	20-100%
87	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 7:30-21:30, Sat 7:00-18:30, Sun 11:00-21:30	20-100%

88	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 7:45-21:30, Sat 7:45-20:30, Sun 11:00-18:30	20-100%
89	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 7:45-21:30, Sat 7:45-20:30, Sun 11:00-18:30	20-100%
90	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 7:30-21:30, Sat 7:30-20:30, Sun 11:00-21:30	20-100%
91	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 7:30-21:00, Sat 7:30-20:00, Sun 11:30-21:30	20-100%
92	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Sat 8:00-21:00, Sun 11:30-18:45	20-100%
93	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:00, Sun 11:30-18:20	20-100%
94	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Sat 6:30-24:00, Sun 10:30-24:00	20-100%
95	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:00, Sun 11:30-21:00	20-100%
96	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:00, Sun 11:30-21:00	20-100%
97	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Fri 8:00-21:00, Sat 8:00-20:00, Sun 11:30-21:00	20-100%
98	Ventilation unit	Fan speed %	**25**	20 %	100 %	Mon-Sat 8:00-24:00, Sun 11:00-24:00	20-100%
99	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
100	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
101	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
102	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
103	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
104	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
105	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
106	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
107	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
108	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
109	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%

110	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
111	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
112	Outdoor ground heating unit	Control point	**27,85**	0 %	100 %		0-100%
113	Outdoor ground heating pump	Control point	**5**	0 %	100 %		0-100%
114	Outdoor ground heating pump	Control point	**5**	0 %	100 %		0-100%
115	Outdoor ground heating pump	Control point	**5**	0 %	100 %		0-100%
116	Outdoor ground heating pump	Control point	**5**	0 %	100 %		0-100%
117	Outdoor ground heating pump	Control point	**5**	0 %	100 %		0-100%
118	Outdoor ground heating pump	Control point	**5**	0 %	100 %		0-100%
119	Outdoor ground heating pump	Control point	**5**	0 %	100 %		0-100%